EVERYDAY SCIENCE

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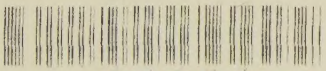

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EVERYDAY SCIENCE

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EVERYDAY SCIENCE

A COURSE OF GENERAL SCIENCE RELATED TO HUMAN ACTIVITIES

BY

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WITH 381 *ILLUSTRATIONS*

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PREFACE

For several years there has been an active movement in educational circles in favour of extending the scope of the science courses usually followed in Secondary Schools. The view held by competent authorities is expressed in three resolutions adopted by the Headmasters' Conference some time ago, namely :

(1) That it is essential to a boy's general education that he should have some knowledge of the natural laws underlying the phenomena of daily life, and some training in their experimental investigation.

(2) That this can best be ensured by giving to all boys adequate courses of generalised science work, which would normally be completed for the ordinary boy at the age of sixteen.

(3) That, after this stage, boys who require it should take up science work of a more specialised type, while the others should for some time continue to do some science work of a more general character.

Though these principles would be accepted as axiomatic by most educationists, it is to be regretted that they have not yet been put into practice in many schools. A Report on Science in School Certificate Examinations just published by the British Association shows that out of about 54,000 candidates who sat for the School Certificate Examination in 1926, 40 per cent. took chemistry as their science subject, 25 per cent. took physics, and 25 per cent. (chiefly girls) botany, while only 2·5 per cent. took general science. As about 3 per cent. only of these candidates propose to proceed to a University or qualify for a subsequent professional examination, and most of the remaining 97 per cent. receive no further education in science, it is evident that the usual courses followed in schools are not adapted to the everyday life and interests of the majority of the pupils, but to the academic requirements of the minority.

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No school course in science can be regarded as complete or satisfactory if it neglects the interests of pupils in the natural world of living creatures around them and their own relations to the life of the community. Even to read newspaper reports of natural events and phenomena intelligently requires a general knowledge of things in the heavens above and the earth beneath, of common plants and animals, of life as a whole, including man and his mastery of Nature. It is with the purpose of providing such a survey of the natural world in which we live and our relation to it that this book has been written.

The general plan of the book conforms to the syllabuses of general or everyday science of the Oxford and Cambridge Schools Examination Board, the Oxford Local Examinations and the Civil Service Commissioners. A syllabus of General Science of School Certificate standard has just been included in the Cambridge Local Examinations schedules, and most of the subjects in this syllabus are dealt with descriptively in this book. The Cambridge syllabus, however, seems scarcely to have been conceived in the spirit of general everyday science for all, but is rather a combination of introductory courses of physics, chemistry, botany, and other subjects of the usual systematic kind.

An attempt is made in this volume to give a broad general survey of the realm of science suitable for use in schools, whether examinations are the proximate or ultimate aim of the teaching or not. Particular attention has been given to contacts of scientific work and results with everyday life, because it is through these that interest is best created in any subject. For this reason the book may appeal to the general reader who desires information upon common natural occurrences and phenomena brought before him from time to time, or wishes to obtain a general idea of everyday applications of science, as much as to the student preparing for an examination in general elementary science.

The subject matter ranges from a description of the vast objects of celestial space to that of the minute structure of the atom. The Universe, Life, and Man are first described, and then an elementary account of man's dealings with objects in

motion and his relations with matter is given. The subjects dealt with can be studied in schools as a progressive course extending over three years, but in order that the book may be equally suitable to the requirements of those teachers who wish to concentrate on certain sections of the subject matter, three separate Parts of the book are available, namely :

Part I dealing with astronomy, geology, and biology.
Part II dealing with elementary physics.
Part III dealing with elementary chemistry.

The Parts may be studied in any order, but in at least one of them the pupil should carry out experimental work. In each Part there are brief historical notes dealing with the progress of scientific discovery, and also references of a biographical character, as well as a set of typical examination questions, many of them from papers set by the Civil Service Commission, the Oxford and Cambridge Schools Examination Board, and other public examining bodies. Thanks are due to those authorities for permission to use questions from such papers.

Particular care has been taken in the selection and preparation of illustrations for the book, and grateful acknowledgment is gladly made to the friends and industrial firms who have been good enough to provide photographs or other pictures for this purpose. The sources of most of such illustrations will be found indicated in the inscriptions to the figures themselves, but special thanks are due to the Macmillan Company, New York, and to the authors of three books published by that firm, who have been good enough to permit the use of illustrations from their books. The three volumes, to the authors of which I am much indebted for this privilege, are *Practical Chemistry*, by N. H. Black and Prof. J. B. Conant ; *Elements of Chemistry*, by Prof. H. N. Holmes and L. W. Mattern ; and *Practical Physics*, by N. H. Black and Prof. H. N. Davis. Mr. H. E. Hadley has also been good enough to permit me to use a number of illustrations from his excellent book, *Everyday Physics*, and a certain number of figures from other books published by Messrs. Macmillan and Co., Ltd., has been included. I am sure that interest in the text will be increased by the inclusion of so many figures illustrating principles or processes.

In conclusion, I wish to express my sincere thanks to Sir Richard Gregory, who suggested the preparation of this book to me and at every stage has generously given me most valuable advice and guidance. I am also greatly indebted to Mr. A. J. V. Gale, M.A., who together with Sir Richard Gregory has read through the proofs and offered many helpful criticisms.

L. M. PARSONS.

December, 1928.

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PART I

THE SKY, THE EARTH, AND LIFE

CHAPTER I

THE STARS, NEBULAE, AND THE SUN

The countless bright objects seen above us in the heavens on a clear night have exercised the thoughts and imagination of mankind during many centuries. With dawning intelligence and an increasing desire to know the " why and wherefore " of things, even primitive man must have marvelled concerning the vast array of far distant points of light. The majesty of the heavenly bodies and the vast regions of space have inspired men's minds with awe and reverence, so that it is no matter for surprise that ancient peoples, such as the Chaldeans 5,000 years ago, worshipped the sun, the moon, and such planets as were then known. The phenomena of comets and of eclipses caused fear and misgiving. Later, in the Middle Ages, a superstitious growth still adhered to the study of the stars, so that the crude alchemy of the chemist had its counterpart in astrology, which dealt with the supposed influence of the heavenly bodies upon the fortunes and destinies of men.

Vanity combined with lack of knowledge caused man to consider that his little world was the centre of the universe, and that all the heavenly bodies, including the sun, revolved around the earth. This, the fundamental idea of the astronomical system of **Ptolemy,** was believed for about 1,400 years, until 1543 when **Copernicus,** a Polish astronomer, showed that the

apparent movements of celestial bodies visible to the naked eye could be best explained by the revolution of the earth and other planets around the sun, with the stellar universe outside this system. Mathematical astronomy took a great step forward with the establishment of the Copernican System, and the century which immediately followed witnessed many other strides in astronomical progress. Although the Italian **Galileo** did not actually invent the telescope, he first used one to such good effect that he proved the revolution of four moons around Jupiter, and showed by observations of sunspots that the sun itself rotates upon an axis.

In 1619, **Kepler,** a German, found that the paths of the planets around the sun are not circles but ellipses, and that the speed at which any planet moves along its orbit is not uniform. Shortly after this our own great mathematician, **Sir Isaac Newton,** showed that it is the attractive force of gravitation which regulates planetary motion and controls the movements of all kinds of matter in space. Newton was not only a mathematician, but also an experimenter, and invented the first reflecting telescope, a class of instrument in which a magnified image is produced by a concave mirror instead of by a lens. Reflecting telescopes of much greater size were made by **Sir William Herschel,** the discoverer of the planet Uranus in 1781, who, earlier in life, was a musician in a Hanoverian military band. With his giant telescope forty feet long, erected at Slough near Windsor in 1789, he discovered thousands of stars and nebulae not known before.

The success of modern astronomy is due not only to the great improvement in telescopes, but also to the use of the camera and the spectroscope. Photographs may be obtained of stars that can never be seen by the eye, since rays that cannot be perceived as light can play steadily upon a photographic plate and produce results if the exposure is sufficiently long. For these time exposures it is necessary to mount the telescope and its attached camera so that they are rotated by clockwork in a direction, and at a rate, to counteract exactly the rotation of the earth.

Real progress in celestial photography dates from the

invention of the dry photographic plate in 1880, and since that time hundreds of millions of stars have been photographed.

THE STARS

On a clear night the heavens appear as a great "inverted bowl" studded with stars. It seems to an observer that he is standing at the centre of a gigantic hollow black hemisphere containing the stars, and this huge spherical space is called the **celestial sphere,** the other half of which is above the remote side of the earth. When visibility is very good, it may be noticed that the greatest concentration of stars is along a broad band called the **Milky Way** or **Galaxy.** This concentration is observed from the other side of the earth also, hence it appears that our stellar universe is shaped somewhat like a huge disc or ring, which may be compared to a grindstone in shape. Our solar system is not far from the centre of this disc, so that we see more stars when looking towards the circumference than when looking up to the flat part.

Many of the stars nearer than those in the vast cluster of the Milky Way are roughly arranged in groups (Fig. 1), and the ancients imagined that the shapes of these groups resembled the outlines of animals or other figures. Thus we have the groups known as Leo (the lion), Cancer (the crab), Capricorn (the goat), Libra (the scales), etc. These groups are called **constellations,** and twelve of them are distributed around the celestial sphere in such a way that the sun appears to pass through them, one after another, during the year. These particular constellations are known as the **Signs of the Zodiac,** and the sun's apparent journey through them is really due to the earth's revolution along its orbit, as explained in the next chapter.

Stars are not all of equal brilliance, the average brightness of the twenty brightest stars being described as the first magnitude, the next in order being those of the second magnitude, and so on. The brightest star in the heavens is Sirius in the constellation of the great dog (Canis Major), and the Pole Star is one of the second magnitude. Stars beyond the sixth magnitude cannot be seen by the unaided eye.

A star of any magnitude appears simply as a point of light, not as a luminous disc of measurable width as in the case of planets. Even the most powerful telescopes fail to resolve a star into anything other than a luminous point, thus suggesting enormous distances between us and the stars, and there is good

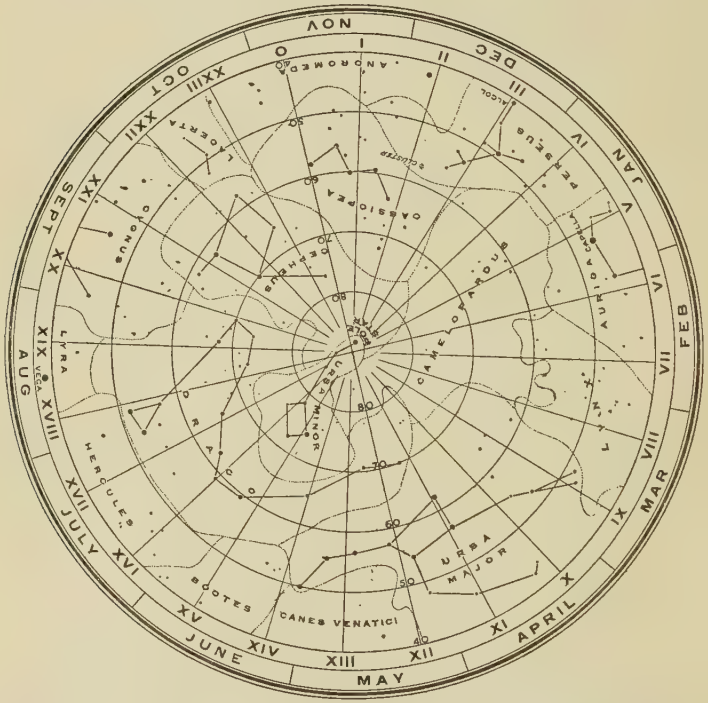


Fig. 1.—Star Groups or Constellations around the Pole Star.

reason for believing that the stars are as far from one another as they are from us.

The distances of the nearer stars can be measured by observations of the apparent shifting of position called **parallax** due to the movement of the earth in its orbit. If the position of a certain star is observed, and noted again six months later, when the earth is at a position on the other side of its orbit,

some 186,000,000 miles away from the position of the first observation, that star is apparently displaced from its first position (Fig. 2). In fact, as the earth moves along its elliptical orbit, the star appears to trace a very minute parallactic ellipse, the apparent size of which depends upon the star's distance. The nearer the star the larger is this ellipse. Calculations based

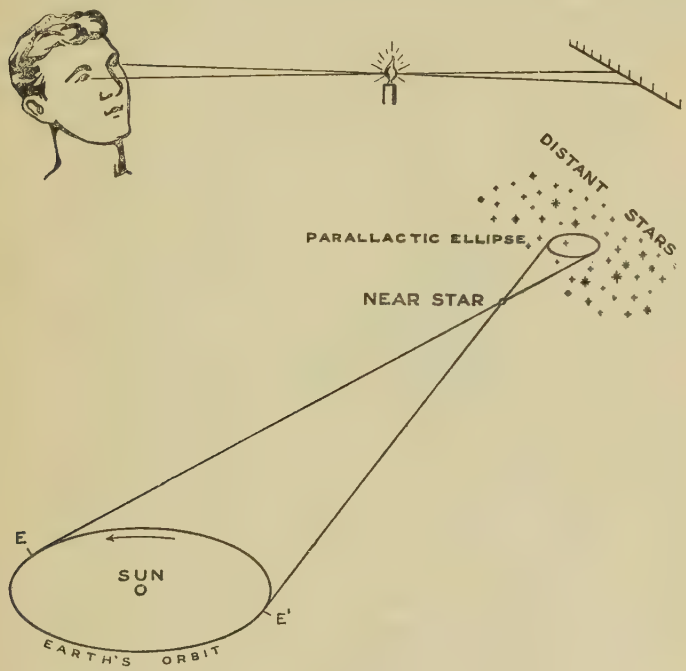


FIG. 2.—PARALLAX,

OR THE APPARENT SHIFTING OF AN OBJECT DUE TO CHANGE IN POSITION OF THE OBSERVER.

upon parallax show that the star nearest to the earth, **Alpha Centauri**, is not less than nineteen billions of miles distant. The parallactic ellipses of even the nearer stars are so small that only experienced astronomers making regular observations with first class telescopes can take such measurements.

The great majority of stars are so far away that their distances cannot be calculated. So vast are the spaces between the

heavenly bodies that mere millions of miles are inadequate; hence other units are employed in astronomy. The distance travelled by light in one year, proceeding at the rate of 186,000 miles per second, is called a **light-year** and is equivalent to six million million miles. The light proceeding from Alpha Centauri takes about four years to reach us, but the greater number of stars are seen by light rays emitted by them scores or even thousands of years ago. Many of the stars we now see may have long since become cold.

At various times star charts and catalogues have been made by competent observers, a very early catalogue being that of Hipparchus made in 125 B.C. If the positions of certain stars as shown on these early catalogues are compared with the positions of the same stars to-day, it is found that they have moved to some extent. The stars have a **proper motion** of their own through space. But it requires centuries for these proper motions to become noticeable, and though in hundreds of thousands of years from now the general pattern of the stars in the sky will be different from that seen to-day, the positions of stars in relation to one another are permanent in our own time, and we regard them as fixed. It is this definite fixed positions of stars and of constellations in our own day that gives such important aid to navigation. For practical purposes the stars remain fixed in relation to one another, and the imperceptible proper motion must not be confused with the daily **apparent motions** of the stars. Almost above the earth's north pole is the **Pole Star,** and the stars near it appear to move in circles around it without going below the horizon. Other stars farther towards the horizon rise and set just as the sun does. All of these apparent motions are due to the earth's rotation.

THE STARS IN NAVIGATION

Since the stars appear fixed with regard to one another, they can be used as objects with which to take the bearings of a ship at sea, provided that the correct place of a certain star on the celestial sphere at a particular date and time be known. The work of calculation and preparation of data concerning the

positions of stars at various dates and times is the business of the mathematicians who prepare the "Nautical Almanac." In order that lists and tables of these positions may be given, some generally used scheme of measurement must be employed. On the earth's surface the position of a place is indicated by means of two co-ordinates—**latitude** and **longitude**—and in astronomy the positions of heavenly bodies on the celestial sphere may be

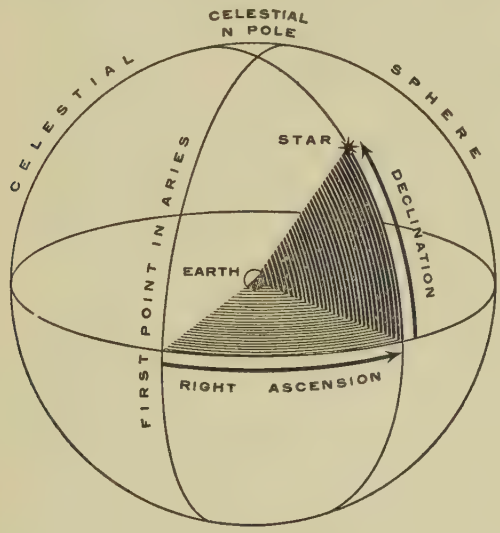


FIG. 3.
THE POSITION OF A CELESTIAL BODY IS DEFINED IN TERMS OF DECLINATION AND RIGHT ASCENSION.

similarly indicated by **celestial latitude** and **celestial longitude.** A more commonly used mode of defining the position of a star is that employing **Declination** corresponding to latitude and **Right Ascension** corresponding to longitude.

The Declination of a star (Fig. 3) is the distance from the celestial equator to the star measured along the hour circle of the star. As in terrestrial longitude we use the Greenwich meridian as the starting position, so in astronomy we use a point (or a great circle through it) on the celestial sphere and called the **First point of Aries** as the starting point. The distance

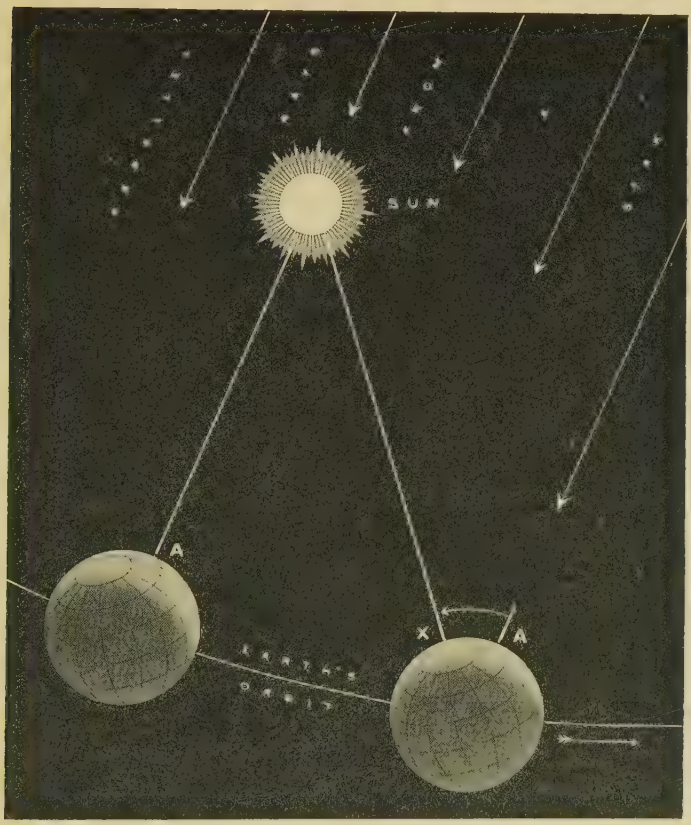
from this point along the equator to the star's hour circle is the Right Ascension of the star. Since the apparent rotation of the star dome is uniform, the Right Ascension is usually expressed as the time which elapses between the crossing of the circle through Aries over the meridian of a place and the crossing of the star's hour circle over the same meridian. The units employed are hours, minutes, and seconds of **sidereal time.** The star chart in (Fig. 1) shows the hours of Right Ascension in Roman figures and also some Declination circles.

In the "Nautical Almanac" the positions of some hundreds of stars are given as seen from any place at any date and time. From such data the navigator can calculate his latitude and longitude. In the northern hemisphere latitude can be determined quite simply without the aid of the "Almanac." Since the Pole Star is practically overhead at the earth's north pole and down on the horizon at the equator, it follows that the angle of elevation of the Pole Star gives the latitude of the place of observation.

SOLAR AND SIDEREAL TIME

Latitude and longitude are not the only measurements in which the use of stars is important. Time is based upon the period taken by the earth to rotate on its axis (Fig. 4). In daily life we use **solar time,** in which the time taken by the earth to rotate once is determined by reference to the sun and is called a day of 24 hours. Since the earth moves forward along its orbit a little each day, any place must rotate through more than 360° to come in line with the sun again, so that the solar 24 hours is really a little longer than the actual time taken by the earth to complete one rotation. Now if the time of rotation is taken with reference to a certain star, **sidereal time** is obtained, and the true period of the earth's rotation is found to be 23 hours, 56 minutes, and 4 seconds, expressed in mean solar units. Sidereal time, though not used by the general public, is useful to the astronomer. Solar time is generally more convenient because the periods of light and darkness at any place are determined by the position of that place relative to the sun and not to the stars.

An important fact concerning solar time must be noted. The earth does not travel along its orbit at a uniform rate, hence the length of the solar day varies slightly. The average,



Drawn by Mr. Scriven Bolton

FIG. 4.—SOLAR AND SIDEREAL TIME.
IN ORDER TO COMPLETE A SOLAR DAY THE PLACE A MUST ROTATE THROUGH MORE THAN 360°.

or **mean, solar day** is taken as the basis of time used in everyday life. Clocks measure mean solar time but sundials, when properly graduated and mounted, measure *true* solar time.

THE CONSTITUTION OF THE STARS

The physical and chemical nature of heavenly bodies is investigated by means of an instrument called a **spectroscope.** Stated quite broadly, this instrument (Fig. 5) is used for the examination or analysis of light emitted by heated objects. The kind of light emitted depends largely upon the chemical nature of the substance and partly upon its physical state, whether it is a glowing vapour or a mass of incandescent solid particles. Most people are familiar with the principle of the spectroscope. When ordinary so-called white light is passed through a triangular piece of cut glass, a band of bright colours is seen ranging

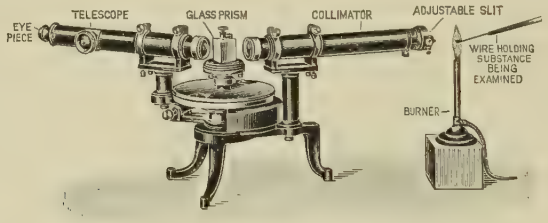


FIG. 5.—A SPECTROSCOPE.

from red at one end to violet at the other. The cut glass produces by refraction what might be termed a rainbow effect. Drops of falling rain do exactly the same with sunlight as the cut glass does, and in either case the band of colours is called a **spectrum.**

A spectroscope is an arrangement employed for the examination of the spectra of glowing bodies. In its simplest form the instrument consists of a triangular glass prism placed between two tubes arranged at the required angle. The remote end of one tube bears a slit for admitting light from the object undergoing examination, while the outer end of the other tube contains a magnifying lens or eyepiece by means of which an observer examines a magnified image of the spectrum obtained. The light after passing through the slit enters the prism and is then **dispersed** into colours according to the nature of the substance supplying the light. Sometimes a complete band of colours is seen, as in the case of the spectrum of sunlight, while in some

other cases there are visible only a few bright coloured lines vertically crossing a dark band. *In general, the spectrum of an incandescent mass of solid particles consists of a continuous band of colours, whereas the spectrum of a glowing vapour shows bright lines in a dark ground.*

If the light from a pinch of common salt vaporising in a bunsen flame is allowed to enter the slit, the spectrum seen consists of two thin yellow lines very close together, and these lines for salt always occur in the same positions. Each vaporised substance has its own spectrum consisting of lines of definite colour and occupying definite positions, so that the spectroscope enables us to learn much concerning the chemistry of luminous objects although they may be millions of miles away.

If the spectroscope is directed to a distant star, what do we observe? The spectrum obtained usually consists of a continuous band of colours somewhat similar to that of the solar spectrum, and numerous dark lines are present. The continuous band of colours suggests that the star consists of incandescent particles, but what of the dark lines? Consider again the case of the spectrum of glowing vaporised salt. Two bright yellow lines were obtained. Now if these lines are seen against a background of brighter light also containing the same substance, and due to a hotter mass, they are perceived as dark lines but occupying the same positions exactly as before. Hence the usual stellar spectra suggest that the stars consist of an intensely hot glowing mass surrounded by vapours containing similar substances at a lower temperature. By noting the positions of the dark lines and comparing them with the corresponding bright lines in the spectra of the terrestrial elements, it is possible for an astronomer to say definitely which of these earthly elements exist in the stellar vapours. These dark lines were discovered in the spectrum of sunlight by a German named **Fraunhofer** as far back as 1814, but their significance was not realised until forty years afterwards (Fig. 6). Hydrogen, iron, sodium, magnesium, and calcium are among the chief elements found in the stars.

The temperature of the stars varies considerably. There is reason to believe that stars originally were in the form of very

attenuated gaseous matter. Gravitational attraction among these particles caused them to come closer together with the development of heat. At a later stage a cooling process sets in and the temperature falls. It appears that in the earlier part of its life history a star is hotter, larger, and less dense than it is during its later existence. The stars are in various

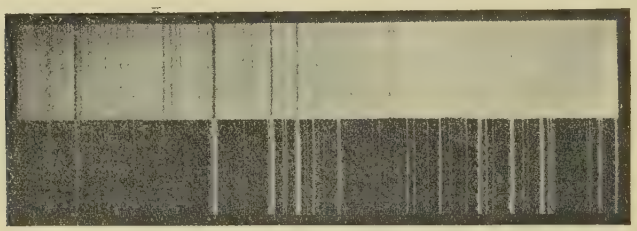


FIG. 6.—SOLAR SPECTRUM.

THE TOP STRIP SHOWS A PART OF THE SOLAR SPECTRUM WITH DARK FRAUNHOFER LINES, AND THE LOWER STRIP AS CORRESPONDING PART OF THE SPECTRUM OF IRON VAPOURISED IN AN ELECTRIC ARC.

stages of development, the hotter larger type being known as **giants,** and the smaller cooler kind as **dwarfs.** Some of the giants are hundreds of times as large as our sun.

Sometimes a dark star revolves around a bright one so that, when it is passing between us and its bright companion, it obscures some of the light, and causes the brightness to vary periodically. The star **Algol** is a **variable star** of this type.

NEBULAE

Distributed among the stellar spaces, but chiefly in the regions outside of the main star streams of our universe, are enormous patches of cloudy luminous material. These are called **nebulae,** and though hundreds of thousands are known to exist, only two, that in the constellation of Orion, and the great spiral nebula in Andromeda, can be seen by the naked eye (Fig. 7). Nebulae resemble the stars in having fixed positions relative to the stars and to other nebulae; and some of them, the so-called "white" nebulae, also resemble stars in the character of their spectra. Thus the spiral nebula in

Andromeda exhibits a spectrum consisting of a continuous band of colours with certain dark bands in addition. Nebulous masses of this type are extremely remote and are probably separate universes of stars. On the other hand, the true nebulae

FIG. 7.—THE GREAT SPIRAL NEBULA IN ANDROMEDA.

or "green" kind show spectra of bright lines only and are therefore masses of luminous gas, chiefly hydrogen, helium, and a substance not yet known among terrestrial elements.

In size and shape nebulae are very varied. Many of them extend across vast spaces measuring millions of miles, while in form some are very irregular, such as the nebula in Orion, others are like rings or discs, and some are gigantic spirals. The

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spiral nebulae are of particular interest, since they represent other universes in which systems of stars are being evolved. From each of such stars a number of separate planets may be thrown off in course of time. According to this theory, a planetary system commenced as a vast mass of luminous vapour in which a whirling movement was caused by gravitation. As the mass cooled and condensed, the whirling motion increased in speed, so that pieces became detached. A similar condensation and increase of speed occurred in each detached mass so that planets and satellites were formed and retained a rotation about their respective axes. Though this hypothesis is a fascinating explanation of the origin of worlds, it is by no means certain that it is true in all respects, and it may be regarded only as a possible solution to the riddle of the universe so far as the forms of planetary systems are concerned. It is probably beyond the reach of man to solve the problem of the origin of matter itself.

Recent mathematical researches suggest that the universe originally consisted of a uniform gaseous substance of extreme tenuity but extending through such an enormous space that light would take hundreds of millions of years to traverse it. Vast condensations of this material occurred at definite spatial intervals with the formation of something like two million gigantic nebulae separated from one another by intervening spaces each equal to more than a million light-years. Further condensation occurred in projecting portions of these nebulous masses, leading to the production of stars similar to our sun. Stars in passing one another exerted a tide-producing force attracting projecting masses which thus became detached and formed planets. The planets in their turn were subjected to tidal forces, with the result that moons or satellites have been produced.

In *Nature* of February 26, 1927, Sir J. H. Jeans summarised and illustrated existing knowledge of the evolution of the universe as follows:—We have in succession:

"1. A uniform tenuous gas of density 10^{-31} and of diameter at least hundreds of millions of light-years.

2. Condensations developing in this gas at about a million

light-years apart, and forming separate nebulae with masses of the order of a thousand million suns.

3. Condensations developing in turn in the arms of these nebulae, and forming stars with masses of the order of our sun.

The faintest nebulae which can be observed photographically in the 100-inch telescope of the Mount Wilson Observatory are of about 18th magnitude, and these must be at the amazing distance of about 140,000,000 light-years. Within this distance some two million nebulae must lie. Dr. Hubble finds that these are fairly uniformly spaced at an average distance of about 1,800,000 light-years apart. To construct a model, take 20 tons of walnuts and space them at about 25 yards apart, thus filling a sphere of about a mile radius. This sphere is the range of vision of the 100-inch telescope ; each walnut is a nebula containing matter enough for the creation of perhaps a thousand million suns like ours ; each atom in each walnut is a solar system with a diameter equal to that of the earth's orbit."

THE SUN

Our existence is influenced more by the sun that by any other body ; in fact, life as we know it would be quite impossible without the heat and light brought by the sun's rays. To this majestic lamp in the focus of our planetary system we owe daylight, the warmth which ripens our crops, and the winds which bring us our rain. If it were not for the sun the earth would be a barren frozen waste unfit for habitation. Our domestic fires are possible, and our machinery is driven by the energy of sunshine that shone, millions of years ago, on the forest trees that are now dug up as coal. This, and much more, the sun does for us, though an average distance of 92,700,000 miles separates us from it.

Less than one two-thousandth part of the heat radiated by the sun is received by the earth, so that the total amount sent into space must be enormous. The temperature of the sun's surface is certainly much higher than that of an electric furnace, and this is above 3500° Centigrade, while the temperature near the centre is probably millions of degrees. Several theories have

been advanced to explain the origin of this heat. Radio-active substances give out a great amount of heat as the radium disintegrates, and it is probable that one factor in maintaining the sun's high temperature is of this nature. Another factor may be changes in atomic structure taking place in the sun's material. It is certain that some such generation of new heat must take place to balance the enormous loss by radiation, otherwise the sun could not have given heat and light for hundreds of millions of years during which the earth has supported living creatures. A certain amount of heat is also obtained from the contraction of the sun's material, since the contraction of gases leads to a rise in temperature. It is probable that each of these factors share, though unequally, in maintaining this life-giving stream of radiant heat and light.

As the distance of the sun is known its size can be calculated by observations of the apparent size of its disc. Its diameter is 866,500 miles, and this means that it has a volume more than one and a quarter million times that of the earth. It is, however, composed of material much less dense than that of the earth, so that in spite of its great size it is only 330,000 times as heavy as our planet.

If a piece of well-smoked glass is placed in front of the eye, the sun appears as a uniformly illumined flat disc, but when viewed through a telescope several interesting features can be recognised. The surface known as the **photosphere** is seen to be a shade darker near the edge, and generally to consist of whitish granular masses which have received the name of "rice grains." These are shown by the spectroscope to be luminous clouds composed of metallic vapours. There also exist various dark irregular patches called **sunspots,** and these appear to be distributed along two broad zones, one on either side of the sun's equator (Fig. 8). North or south beyond these zones towards the poles the photosphere is free from spots. The size of sunspots varies considerably, some of them being merely hundreds of miles across while the larger ones may be thousands of miles in width, and millions of square miles in area.

Examination of a sunspot shows that it consists of a dark central area surrounded by a less dark zone, the whole being

fringed by bright whirling clouds or **faculae.** The dark patches (Fig. 9) are areas of spirally descending vapours, cooler than the surrounding photosphere, though still very hot. They appear dark by contrast. Spectroscopic calculations show that the speed of these whirling gases, largely hydrogen, is terrific, anything up to 200 miles per second. The spots all move in

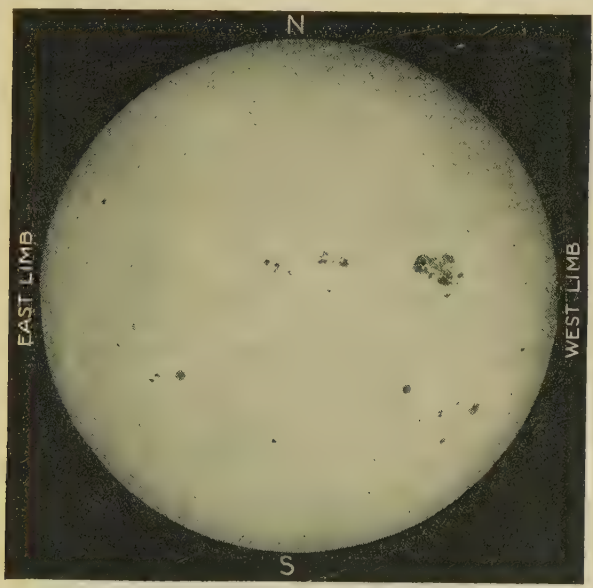


FIG. 8.—THE SUN'S PHOTOSPHERE WITH GROUPS OF SUN SPOTS, ONE ON EITHER SIDE OF THE SOLAR EQUATOR.

one direction from left to right across the face of the sun, disappear round the right edge, and, when they last long enough, re-appear on the left edge some days later.

This proves that the sun rotates on an axis, but a remarkable fact in this connection is that the spots nearer the sun's equator complete the journey in less time than do spots in higher latitudes. From this it follows that the sun is not a rigid solid body, since, if it were, any one spot would give the same rotation period as any other spot. The average period of rotation is

$25\frac{1}{3}$ days actually, though it appears to be $27\frac{1}{4}$ days on account of the earth's movement along its orbit.

The terms east and west are used to describe the sun's edges or limbs as we see them, the eastern edge being to the left

Drawn by Mr. Scriven Bolton.

FIG. 9.—STRUCTURE OF A SUNSPOT AND THE SURROUNDING PHOTOSPHERE.

and the western edge to the right. Really, the sun rotates in a direction similar to the earth's own rotation.

Sunspot activity shows various degrees of intensity. In general, the number of spots increases to a maximum, then decreases to a minimum, and again rises towards a maximum. The period between two successive maxima is about eleven

years, so that the increase and decline occur in a definite cycle. Though there may be no relation between our earthly weather and sunspot activity, there is certainly some definite connection between sunspot maxima and magnetic storms which disturb electro-magnetic instruments on the earth. Also displays of **aurora**, an electrical phenomenon seen in high latitudes, are more common during a sunspot maximum.

What is the chemical composition of the sun? The answer to this question is given by the spectroscope. The solar spectrum, as that of a star, consists of a bright band of colours crossed vertically by very numerous dark "Fraunhofer" lines. Comparison of the positions of these lines show that quite a large number of substances we know on the earth exist also in the sun. Among the more commonly known of these are iron, copper, zinc, lead, silver, aluminium, oxygen, hydrogen, and carbon. The photospheric clouds float in an atmosphere of metallic vapours. Some lines in the solar spectrum cannot be matched by any in the spectra of terrestrial elements. Thus, an unknown substance which has been termed "coronium" occurs in the outermost solar atmosphere, called the **corona**, seen during a total eclipse of the sun.

Many other features of great interest may be observed during a total eclipse. When the intense glare of the photosphere is obscured by the moon, a gaseous zone lower than the corona but rising to 10,000 miles above the photosphere is seen. This is known as the **chromosphere** and is composed mainly of hydrogen which projects upwards in places as deep red **prominences** which may extend for hundreds of thousands of miles beyond the chromosphere (Fig. 10). Some of these prominences resemble huge tongues of flame, and the spectacle is grand in the extreme. Although the eye in the ordinary way can see these features only during a total eclipse, spectroscopic means have now been found by which the prominences can be studied at any time.

Another recent development of spectroscopic investigation is the study of elements in the sun one at a time by means of an apparatus called a **spectroheliograph.** In principle this is a selective spectroscope which enables an astronomer to photograph those solar clouds which are composed of one element

only, say hydrogen, or calcium—to obtain, as it were, a picture of the sun painted with a single pigment. It is impossible to give here any adequate description of the immense strides made in astronomical science by means of the spectroscope and its modifications.

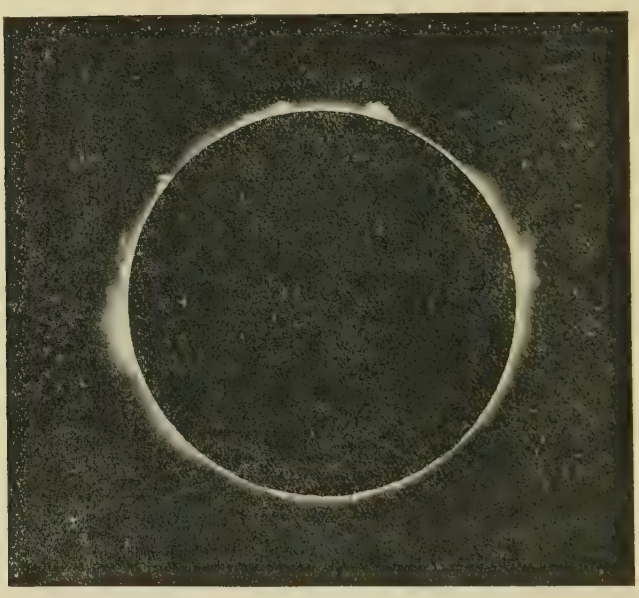


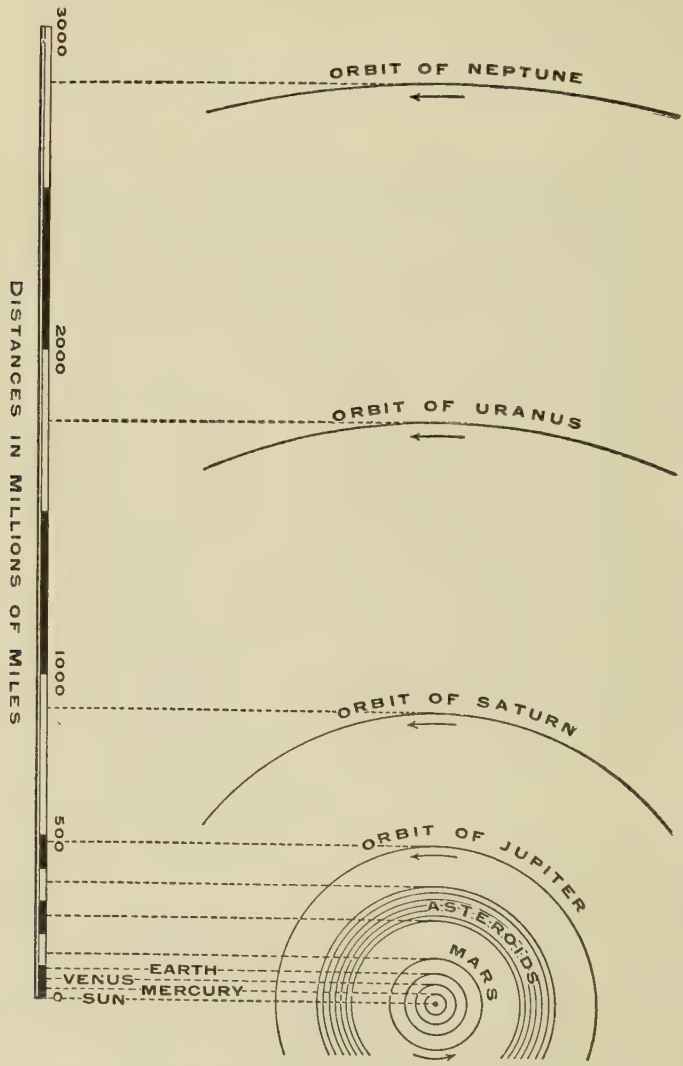
FIG. 10.—TOTAL ECLIPSE OF THE SUN
AS PHOTOGRAPHED AT GIGGLESWICK, YORKSHIRE, ON JUNE 29, 1927.
(By kind permission of the Astronomer Royal.)

As in the case of the stars, the sun has a proper motion through space. Accompanied by its attendant system of planets it is moving towards the constellation Hercules. Its apparent motions, daily through the sky, and yearly through the signs of the Zodiac, will be considered later.

CHAPTER II

PLANETS AND PLANETARY MOTION

As the sun moves through space it is accompanied by several planets, or 'wanderers,' each of which revolves along its own orbit (Fig. 11). Proceeding outwards away from the sun the planets are: **Mercury, Venus,** the **Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.** There is also a large number of planetary fragments revolving along paths situated between the orbits of Mars and Jupiter, and the name **asteroids** or **minor planets** has been given to this group of smaller bodies. All of the major planets from Mercury to Saturn inclusive were known to the Ancients, and there is no record as to when or by whom they were first discovered. Sir William Herschel, in 1781, while exploring the heavens with a telescope of his own construction, attained the hitherto unknown achievement of discovering a new planet. This was given the name **Uranus.** Many years afterwards careful mathematical observations of its movements in its orbit led to the conclusion that some still more remote heavenly body was exercising a disturbing gravitational influence upon it. This more distant object proved to be the planet **Neptune,** the discovery of which in 1846 ranks as one of the finest triumphs of mathematical science. A young Englishman named **Adams** and the French mathematician, **Leverrier,** independently worked at the problem, Adams being the first to arrive at the true position of the new planet. The Englishman, however, was hampered by lack of sufficiently powerful telescopic aid, and though he passed on his information to others, his work was not taken seriously. Leverrier also lacked the necessary instrumental aid, but communicated his result to the Berlin astronomer Galle who, possessing an up-to-date star chart, quickly found the



Drawn by Mr. Scriven Bolton.

FIG. 11.

THE RELATIVE DISTANCES OF THE PLANETS FROM THE SUN.

new planet by means of his powerful telescope, almost exactly in the position calculated for it.

With the exception of Neptune, the distances of the planets from the sun are according to a simple mathematical relation known as **Bode's law.** If 4 be added to the numbers 0, 3, 6, 12, 24, 48, 96, and 192 we obtain the series 4, 7, 10, 16, 28, 52, 100, and 196. These figures represent approximately the relative distances of the planets Mercury to Uranus respectively, including the asteroids, from the sun. In fact, the minor planets, some 1,600 of which are now known, were discovered by attention being directed to the fact that no planet had been found to occupy the position represented by the number 28 in the series. The first—and the largest—of the asteroids, discovered on January 1, 1800, has been named Ceres, and its diameter is about 480 miles, but the brightest is Vesta, which has a diameter of about 240 miles. Some of these bodies are a little larger but all are very small compared with the major planets.

It will be observed that if the numbers in the series given above be divided by ten, the figure representing the earth's distance from the sun is then unity, and it is an easy matter to calculate roughly the distance of any other planet by multiplying the earth's mean distance from the sun, 92,700,000 miles, by the number corresponding to the planet in question. Thus 5·2 is the number representing Jupiter's position, and $92{,}700{,}000 \times 5{\cdot}2$ gives 482,040,000 miles as the approximate distance of Jupiter from the sun.

Neptune is 2792 millions of miles distant from the sun and takes nearly 165 years to complete one revolution along its orbit, while Mercury, the nearest member of the system, is 35,900,000 miles distant and performs its revolution in 88 days.

Unlike a star, which appears always as a point of light, a *planet exhibits a definite more or less circular disc*, and when the distance is known, observations of the apparent size of its disc supplies the necessary information for the calculation of the planet's size. Proceeding outwards from the sun, the first three planets—Mercury, Venus, and the Earth are of increasing size, but then comes Mars, which is considerably smaller than the Earth. The size then increases enormously, reaching greatest

proportions in Jupiter, the volume of which is equal to 1230 Earths, and then decreases again, both Uranus and Neptune being considerably smaller.

In his book *The Vault of Heaven*, Sir Richard Gregory gives a description of the solar system which enables one to form a clear idea of both the distances and sizes of the planets. He says: "The Earth is approximately eight thousand miles in diameter. Let us represent this by one foot and construct an imaginary Solar System on the scale of one foot to eight thousand miles. The dome of St. Paul's Cathedral, more than one hundred feet in diameter, is a fitting representation of a hemisphere of the Sun. Mercury would be proportionally represented by a baby's head at Chancery Lane; Venus, by a globe rather less than one foot in diameter revolving in a path at the distance of Charing Cross from the Cathedral dome; the earth by a one-foot globe at Buckingham Palace; and the moon a cricket ball circling round her at a distance of thirty feet. Mars, a man's head, travelling in a circle having for its radius the distance from St. Paul's to South Kensington Museum, the minor planets, or asteroids, small shot, revolving at the distance of Hammersmith; the radius of Jupiter's orbit would be just beyond Richmond, the planet itself being a globe eleven feet in diameter; Saturn a nine-foot globe would be at Staines, near Windsor, and would move round St. Paul's at this distance; Uranus would be a four-foot globe at Reading; and Neptune, a globe four and a half feet in diameter, would have for the radius of his orbit, the distance from London to Oxford."

On this scale the nearest star would be at a distance of 500,000 miles. Another example may help to emphasize these enormous celestial distances. If an inch be taken to represent the distance of the earth from the sun, then on this scale the nearest star would be about $3\frac{1}{4}$ miles away.

Mathematical calculations involved in the determination of the distances, orbits, sizes, and masses of planets are of too complicated a character to be described here, but the chief results of such calculations are summarised in the table which follows:

Name.	Average diameter in miles.	Average distance from sun in millions of miles.	Period of revolution in days.	Period of rotation.	Number of known satellites.
Mercury	2992	35·9	88	88 sidereal days	—
Venus -	7660	67	224·7	Not known definitely	—
Earth -	7914	92·7	365·3	23 hr. 56 min.	1
Mars -	4200	141	687	24 hr. 37 min.	2
Asteroids	243 (Vesta)	259	1600 (average)	—	—
Jupiter -	85,000	482	4,332	9 hr. 55 min.	9
Saturn -	71,000	884	10,759	10 hr. 14 min.	10
Uranus -	31,700	1,780	30,687	unknown	4
Neptune	34,500	2,780	60,127	unknown	1

If any of the other planets are capable of supporting life as we know it, they are Venus and Mars, which are like the earth in several ways. For example, the Martian day is only a little longer than ours, seasonal variations are probably very similar, and there is a definite atmosphere. The period of a planet's rotation on its axis is measured by observations of surface markings, which are very clear in the case of Mars. Venus, much nearer the sun, has a dense atmosphere and is so bright that no special permanent markings have been found with which to obtain the time of its rotation. Mercury, still nearer the sun, apparently has no atmosphere, and observations of certain lines believed to be cracks have given its rotation period as 88 days, the same time as that required for its revolution. Uranus and Neptune being very remote, and their surfaces indistinct, their rotation periods have not been determined.

The physical conditions of the various planets differ considerably. The first four, Mercury to Mars inclusive, have a fairly high density, about five times that of water, and appear to be solid globes, but the density of the outer members of the system is much less, being least in the case of Saturn, which is considerably lighter than a globe of water of the same size. It is probable that these larger less dense planets are composed mainly of vapours surrounding a semi-liquid interior. Though all of

the planets are relatively cool and are seen by reflected sunlight, the more remote members may contain much more internal heat than those nearer the sun.

MOTIONS OF THE PLANETS

All of the planetary orbits lie nearly in the same plane, and the planets themselves all revolve in the same direction around the sun. The orbits are **ellipses,** or oval figures, though most of them are nearly circles. That of Mercury, however, is more eccentric or elongated, so that this planet's distance from the sun varies by so much as fourteen millions of miles during a complete revolution. Since the movements of the planets are controlled by gravitation and the orbits are elliptical, it follows that the velocity with which a planet moves along its orbit varies, being greatest when the planet is nearest to the sun, or in **perihelion.** These facts were discovered by Kepler, the German astronomer, who also showed that the square of the revolution period is proportional to the cube of the planet's distance from the sun. These relations between planetary orbits, velocity, and distance are generally known as **Kepler's Laws.**

The orbits of the inferior planets, Mercury and Venus, lie inside that of the earth, so that one of these two planets occasionally comes between us and the sun, and is then seen as a dark spot on the sun's surface. In the case of Venus, these **transits** are of interest as they have afforded one means of determining the sun's distance from the earth. Another result of the inferior position of these orbits is that Mercury and Venus both exhibit **phases** similar to those of the moon. At certain positions these planets are visible as complete discs, at other positions as half discs, and when they are nearly between us and the sun they appear as crescents. The superior planets outside of the earth's orbit are always seen as complete discs.

Besides the planets, other celestial bodies, including satellites or moons attached to planets, **comets,** and **meteoric swarms,** move along definite paths or orbits. In the case of Jupiter and Saturn, which have 9 and 10 satellites respectively, it is interesting to note that one satellite of each exhibits *retrograde* motion ;

that is, revolves around its planet in a direction contrary to that of all the other satellites. The four moons of Uranus, also the one known moon of Neptune, are all retrograde compared with the usual direction of the majority of planetary satellites.

Drawn by Mr. Scriven Bolton.

FIG. 12.—THREE POSITIONS OF THE PLANET SATURN ILLUSTRATING VARIATION IN THE APPEARANCE OF THE RINGS.

Though not a satellite in the ordinary sense, the three rings of Saturn (Fig. 12), consist of innumerable solid particles revolving in streams around the planet. The aspect of the

rings, as seen from the earth, alters from time to time. When Galileo first observed Saturn, he did not recognise its rings, but thought the planet had two moons close to it. Later, the rings were edgewise to the earth and Galileo could not see them at all, so he was worried because what he thought were moons had disappeared. It was not until some fifty years afterwards that the ring system of Saturn was understood. Our own satellite,

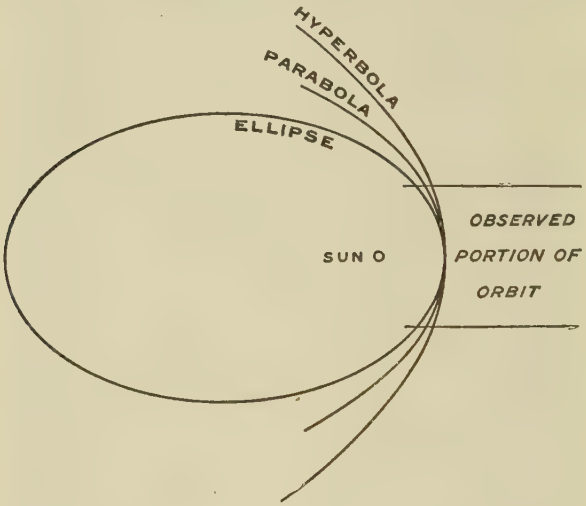


FIG. 13.—DIFFERENT SHAPES OF ORBITS.

the moon, exerts a considerable influence upon human affairs and will be considered later in connection with the earth.

Comets consist of very attenuated luminous matter extending over great volumes of space, some of the larger ones attaining the enormous length of more than 50 million miles. A comet's material is more concentrated in the part known as the head, while the matter forming the tail is so widely diffused that stars and other objects are clearly visible through it. The total mass or amount of matter is small though the volume is so great, hence the density is very low. These celestial visitors rush in from outer space, pass around the sun and then recede, the whole

journey being along a definite orbit. Those which return at regular intervals, such as **Halley's Comet,** which visits us every $76\frac{1}{3}$ years, move along orbits which are still elliptical though very eccentric or elongated (Fig. 13). There are many, however, which move along orbits that are **parabolas,** and these comets, once they have passed the sun, never return.

Shooting stars are pieces of matter, usually quite small, which are attracted from outer space into the earth's atmosphere, when they become white hot through friction with the air. **Meteors** or **fireballs** are similar in character to shooting stars but brighter. Usually these objects vaporise in the air, but occasionally one reaches the ground, when it is found to be composed mainly of nickel and iron. Great numbers of these fragments travel in swarms, and when the earth's atmosphere encounters such a swarm a large shower of ' stars ' apparently radiating from a point is visible. Every year, about the middle of November, the earth encounters a swarm which is evidently proceeding along an orbit which crosses that of the earth during that month.

THE EARTH

Our planet is not properly spherical since rotation on its axis has caused the equatorial portions to bulge outwards at the expense of the polar regions, which have been very slightly flattened. The equatorial diameter is about 7927 miles, while the polar diameter is 27 miles less. Though the earth is frequently described as an oblate spheroid, this is scarcely correct, since pendulum experiments connected with the force of gravity at various places on the surface show that the earth is an irregular ball having a form peculiar to itself. It is more correctly described as a **geoid.** The surface irregularities, mountain ranges and ocean hollows, are very small compared with the diameter of the earth. The highest peaks in the Himalaya are about five miles above, and the deepest parts of the Pacific Ocean are the same distance below standard sea-level, which is defined as the average height of the tide at Liverpool.

The oceans and seas constitute a relatively thin water covering or **hydrosphere** occupying about three-quarters of the earth's surface. The continental masses forming the remainder are so

arranged that they form an almost continuous ring of land near the north pole and taper to pointed extremities in the southern hemisphere, an arrangement which has suggested the theory that the earth is somewhat like a tetrahedron with curved faces. Land and sea areas are in nearly all cases diametrically opposite one another, as can be easily observed by reference to a geographical globe. The results of the distribution of land and sea areas are described fully in text-books of geography, but the movements of the planet must now be considered.

THE EARTH'S ROTATION AND THE DETERMINATION OF TIME

The rising and setting of the sun and of those stars which go below the horizon are due to the rotation of the earth on its axis once in 24 hours. The true period of rotation is determined by observation on stars as explained in the previous chapter, where the importance of mean solar time is also emphasised. The periods of daylight and darkness at any place are determined by the relation of that place to the sun's rays. As a place is carried by the earth's rotation from darkness into the light, the sun appears to rise above the horizon. During some hours which follow, the sun appears to move southwards and rise higher in the heavens until it reaches its highest position for that particular day, when it is noon, natural time (*i.e.* not conventional summer time), for that place. The shadow cast by a vertical stick in the ground is then shorter than at any other time of that day, and extends in a north and south direction. The shadow indicates the noon line or **meridian** of the place, and the sun is said to cross or transit the meridian at noon. How high the sun rises above the horizon on any day, and how short the shadow is, depend upon the latitude of the place and upon the season. The sun is always vertical at noon above some place within the tropics, but is never elevated more than 62° at London. For reasons which are discussed later in connection with the seasons, the sun's noon elevation at London varies from 15° in winter to 62° in summer.

The sun having 'crossed the meridian' of a place then appears to move towards the west and descend until it 'sets' or goes

below the horizon. The place is then carried into the darkness, and experiences night. Owing to refraction, or bending of light by the earth's atmosphere, dawn occurs a little before the sun actually makes its appearance above the horizon, and twilight lasts for some time after it has set. These refraction effects are more pronounced in higher latitudes where the sun's rays, being more oblique, pass through a greater thickness of air. Within the tropics, daylight and darkness come quickly.

The sun's apparent daily motion through the heavens being due to the earth's rotation, it is obvious that when it is noon at one place it will be before noon at any other place farther to the west, and afternoon at more easterly places which have been carried farther round towards the darkness and night. Distance west or east of a given line is expressed by **longitude**, and the given standard of reference is the north and south line or meridian through Greenwich. If this line is extended to meet the earth's poles, we have a large semi-circle and all places on this line have the same time. When it is noon at Greenwich it is also natural noon at many other places, three other towns approximately on the Greenwich meridian being Grimsby, Newhaven, and Havre. But most places are not on the Greenwich meridian and have a different natural or **local time.**

Since there are 360° in one complete rotation, it follows that *every* 15° *of longitude means a difference of one hour.* Thus Truro in Cornwall is about 5° west of Greenwich, so that if it is noon at Greenwich the local time at Truro is 11.40 a.m. Another twenty minutes must elapse before the sun crosses the meridian of Truro. What time will it be at Moscow, $37\frac{1}{2}$° east longitude, if it is noon at Greenwich? Since 15° is equivalent to one hour, $37\frac{1}{2}$° means $2\frac{1}{2}$ hours. Moscow being east of Greenwich has had its noon and is moving towards night, hence the time there is 2.30 in the afternoon.

If every place adopted its own local time, the co-operation necessary for transport, trade, etc., would be extremely difficult. It would be almost impossible to arrange a railway time-table. Some system of common time over large areas must be employed, consequently in Great Britain and Western Europe Greenwich time is used Irish time, which is about 25 minutes behind that

of Greenwich, is determined by the longitude of Dublin. In the countries of Central Europe, also in Scandinavia and Italy, Central European time, which is one hour in advance of Greenwich time, is employed. The United States, extending through more than 70° of longitude, has adopted five time belts, the time of any belt being one hour different from that of the adjacent belt.

So far, we have considered only the time at fixed places on the earth's surface, but what of time in relation to a travelling object, a ship for example? When sailing eastwards a ship goes to meet the sun, so that dawn occurs a little earlier than it would do if the ship were at rest. The period of time between two successive risings of the sun appears a little less than the earth's rotation period; the days are shorter and by the time the ship has reached the far side of the earth an extra day has been gained. On the other hand, should the ship be sailing westwards the days are slightly longer since sunset is delayed, and a day is lost by the time the ship reaches the other side of the earth. The calendar must be adjusted and this is done when a ship crosses longitude 180°, for this reason called the **date line.** If the ship is sailing eastwards a day must be taken off, but if the course is westwards a day must be added. It is easy to understand this adjustment by remembering that the earth makes a complete turn on its axis from west to east in a day. If, in addition, a journey is made around the world from west to east, then a day or one extra rotation has been added. If the journey is from east to west a day is lost.

As we have seen, when the longitude is known, local time can be found. Conversely, if local time is known the longitude of a place can be ascertained provided correct Greenwich time is also obtainable. On ships, accurate chronometers give Greenwich time, and local noon can be found by noting the time of the sun's highest position in the heavens. The difference between the local time and that of Greenwich gives the longitude, according to the relation 1 hour of time means 15° of longitude.

The consequences of terrestrial rotation are not confined to matters of time. Air being a fluid, the directions of the permanent winds are influenced by rotation. The heated air above the equator rises and the cooler air of higher latitudes flows in to take its place. If the earth were stationary, these inflowing winds

would blow directly from the north and from the south, but rotation causes them to flow from the north-east and south-east respectively. These particular winds are known as the **Trade Winds.** Similarly, other winds blowing in the latitudes of the British Isles flow from the south-west and not directly from the south as they would do if the earth did not rotate. This means that Great Britain receives rain-bearing winds from the Atlantic instead of drier winds from France, a matter of considerable

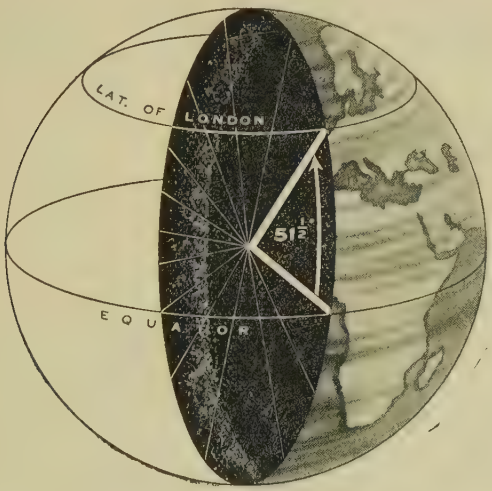


FIG. 14.
THE ANGLE OF 51½° AT THE CENTRE OF THE EARTH MEASURES THE LATITUDE OF LONDON.

importance in connection with climatic conditions. A less apparent result of rotation is the *tangential velocity* acquired by objects on the earth's surface. The widest part of the earth, the equatorial region, rotates at a speed about 1000 miles per hour, and objects on it there travel at the same rate. Fortunately gravitation is greater than this tangential velocity, otherwise objects would fly into space. Theoretically, the velocity at the poles is zero, and in temperate latitudes as in the British Isles the speed of rotation is about 500 miles per hour.

Distance north or south of the equator is called **latitude,** the

equator itself being the line of reference or position from which latitude is measured. If a person commences at London (Fig. 14) to travel southwards along the Greenwich meridian and continues until he reaches the equator, he will have journeyed through an arc of a circle which is opposite an angle at the centre of the earth. This angle, which in the case of London is $51\frac{1}{2}°$, measures the latitude of the place. Distances on the

Drawn by Mr. Scriven Bolton.

FIG. 15.

THE CONNECTION BETWEEN LATITUDE AND QUANTITY OF HEAT RECEIVED PER SQUARE MILE. THOUGH THE BEAMS *x* AND *y* ARE EQUAL, THEY SPREAD OVER DIFFERENT AREAS ON THE EARTH.

surface are proportional to the angles at the centre, and as the earth is not properly spherical the average surface distance equivalent to one degree of latitude is 69 miles. Given the latitude of a place it is quite easy to calculate its distance from the equator. Thus, in the case of London the distance is $51\frac{1}{2} \times 69$, or $3553\frac{1}{2}$ miles. The latitude of a place is found by observing the elevation of the Pole star as explained in the

previous chapter. Observations on other stars will serve, but in that case reference must be made to the "Nautical Almanac" for correct positions, etc. Just as longitude determines the local time, so latitude is a vital factor of the climate at any place.

Owing to the curvature of the earth's surface the sun's rays strike the ground at different angles, vertically at places within the tropics, and very obliquely at places near the polar regions. Where the rays strike vertically (Fig. 15), there will be much more heat received per square mile than at places where the rays meet the ground at a much smaller angle. Two equal beams of sunlight, x and y, produce very different temperature results because in one case x the same quantity of heat is spread over a bigger ground area than in the other case y. *The higher the latitude the less heat is received per square mile.* But the amount of heat received at most places differs at different times during the year, because the angle of reception varies with the seasons. This variation is more pronounced in high latitudes than within the tropics where the sun's rays are always nearly vertical.

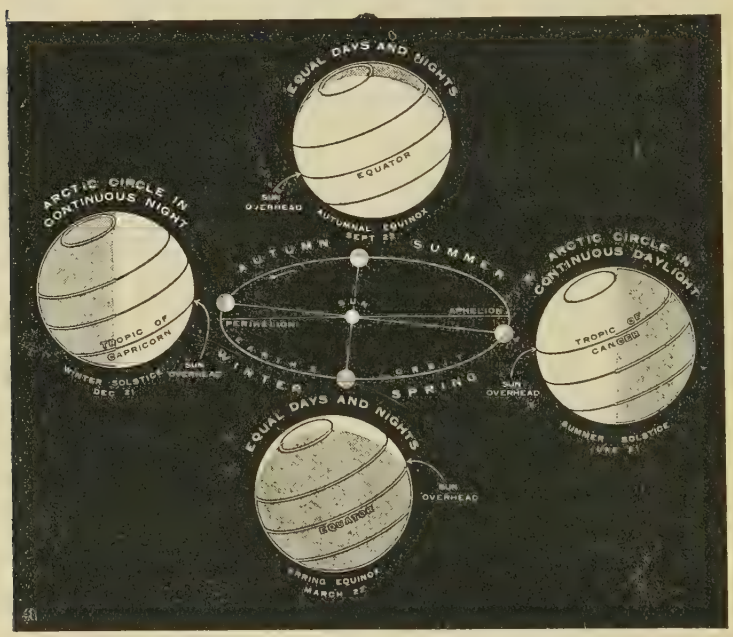
THE EARTH'S ORBIT AND THE SEASONS

The earth performs one complete journey along its orbit around the sun in $365\frac{1}{4}$ days. The calendar is adjusted by adding an extra day once in four years, thus producing a 'leap year' with the extra day in February. The earth's orbit being an ellipse and the sun situated in one focus, the earth is nearer to it sometimes than at other times, the average distance being 92,700,000 miles. It so happens that the earth is nearest the sun, or in **perihelion,** in December and about 3,000,000 miles further away at **aphelion** during June, hence the higher temperature of summer in the northern hemisphere is not the result of smaller distance from the sun. Within the tropics the temperature is much the same all the year round, but in higher latitudes there are distinct seasonal variations (Fig. 16).

These seasons are the result of three essential factors: (1) *the revolution of the earth around the sun*; (2) *the earth's axis being inclined* $66\frac{1}{2}°$ *to the plane of its orbit*, and (3) *the axis retains this position as the earth moves along its orbit.*

Though the axis does alter its position slowly, it requires thousands of years for such alteration to produce appreciable changes in seasonal variations. In our own time, the northern extremity of the axis continues to point approximately towards the Pole star.

Now consider the two positions of the earth in its orbit on June 21, and December 21, respectively. Since the sun is so



Drawn by Mr. Scriven Bolton.

FIG. 16.

THE CAUSE OF SEASONAL VARIATION IN LATITUDES BEYOND THE TROPICS. NAMES OF SOLSTICES AND EQUINOXES REFER TO CONDITIONS IN THE NORTHERN HEMISPHERE.

far distant, the rays which strike the earth are parallel, hence those which fall on the equator do so at an angle different from that of rays which fall on higher latitudes, as we have seen. In June the rays fall perpendicularly along the Tropic of Cancer and other rays illumine the north pole, so that the region within the Arctic Circle remains in the light throughout the twenty-four hours. This is the period of the **midnight sun** seen in the far

north. At this time, in the latitudes of Great Britain, the sun remains above the horizon longer and passes through a greater arc than at any other time of the year. But though it is summer for us, it is winter for similar latitudes in the southern hemisphere, where the sun's rays fail to reach the south pole, which thus remains in darkness for some months. Six months later conditions are reversed, the south pole receiving the sun's rays, while the north pole remains in darkness. The sun is then directly overhead of the Tropic of Capricorn ; it is summer in the southern hemisphere and winter in the northern. After December 21, the sun appears to move northwards away from the Tropic of Capricorn and slowly approaches the northern tropic.

Thus the two tropics are the turning positions of the sun. The change is not abrupt, the sun apparently remaining above each tropic for a day or two, hence June 21, is called the **summer solstice** and December 21, the **winter solstice.** The summer solstice is not the hottest time of the year for Britain, though it is astronomically mid-summer. In our latitudes the hottest period occurs in July or even August, after the ground, etc., have been thoroughly warmed by the summer sunshine.

What about the intermediate positions of the earth on March 21 and September 21 ? At these dates the sun is directly overhead at the equator, and neither polar region has any advantage over the other. In March it is spring in the northern hemisphere, which is then advancing towards its summer, and, of course, it is autumn in the southern hemisphere, which is moving towards its winter season. On these dates the sun is above the horizon twelve hours and below it twelve hours. The daylight and darkness periods are equal except for dawn and twilight effects. The sun rises at 6 a.m. and sets at 6 p.m. natural time. Since these diurnal periods of night and day are roughly equal, these dates are called the **equinoxes,** March 21 being the **vernal equinox,** and September 21 the **autumnal equinox.** Owing to dawn and twilight effects, the periods of light and darkness are really *equal* some days before March 21, and a little after September 21.

Apart from these important seasonal variations, the apparent yearly movement of the sun through the heavens is another result of the earth's journey along its orbit. We are already at

so great a distance from the sun that the vastly greater distances from the sun to the stars cannot be perceived. It appears to us that the sun is moving through the constellations or star groups (Fig. 17). As the earth moves forward on its orbit, the sun appears to move in the course of a year through the principal groups of stars called the twelve **Signs of the Zodiac.** On June 21, the sun appears to be in the sign of Cancer, the Crab,

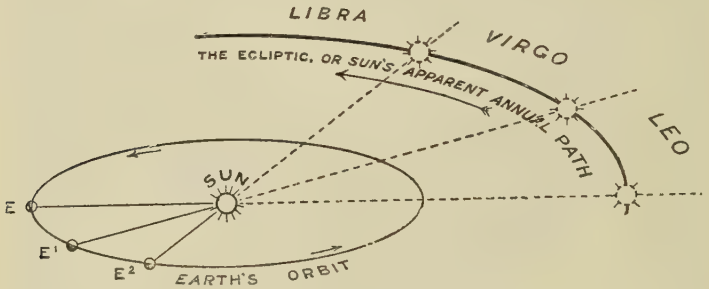


FIG. 17.
THE SUN'S APPARENT MOTION THROUGH THE SIGNS OF THE ZODIAC.

hence the name given to the northern tropic above which the sun is vertical at that date. Similarly, the sun appears to be in the sign or group called Capricorn, the Goat, on December 21 (hence the name of the southern tropic), in the group Aries at the vernal equinox, and in Libra at the autumnal equinox.

THE MOON

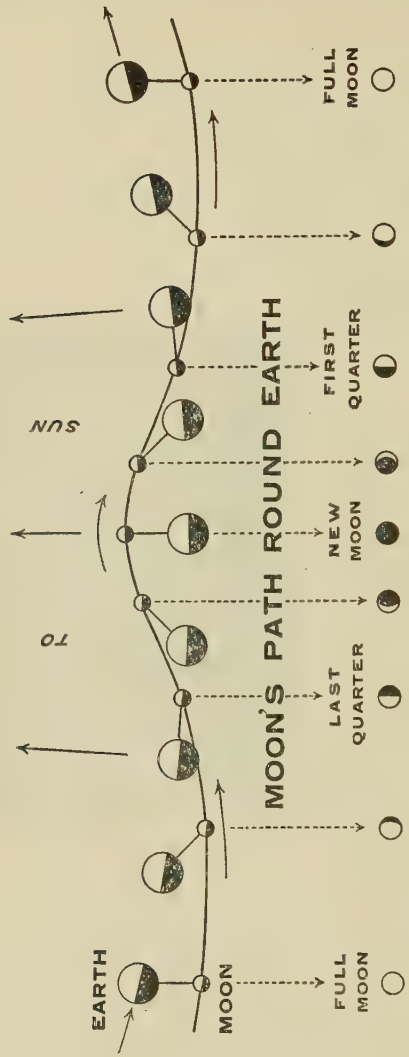
The earth's satellite is very much nearer us than any other heavenly body, its average distance being 238,850 miles. Its orbit is slightly inclined to that of the earth and is rather eccentric, so that when the moon is in **perigee,** or its nearest position, it is some 31,000 miles nearer than when it is in **apogee** or its most remote position. The time taken by the moon in performing one revolution is $27\frac{1}{3}$ days as determined by reference to a star, but if taken with reference to the sun, owing to the movements of the earth the time which elapses between two successive 'new' moons is $29\frac{1}{2}$ days, and this period is called a **lunar month.** In ordinary daily life, however, we use the more

convenient **calendar months** containing a number of complete days.

The moon rotates on its axis once in $27\frac{1}{3}$ days, the same time in which it revolves around the earth, and the result of this is that *only one side of the moon is ever seen by us.* Place some mark on a tennis ball, hold the ball and carry it around a chair always keeping the mark on it facing the chair, and you will realise that the ball has rotated on its axis once while it has also revolved around the chair once. As a matter of fact, we see a little more than half of the moon, as we obtain views a little farther towards the moon's poles on account of its orbit being sometimes above, and sometimes below the plane of the earth's own orbit. The moon's rate of travel along its orbit varies, and this enables us to see just a little bit farther round the edges. These slight variations of the lunar surface presented to our view are called **librations.**

FIG. 18.—THE MOON
ABOUT EIGHT DAYS AFTER THE PERIOD OF NEW MOON.

The part of the moon's surface which we can see is extremely beautiful when viewed through a telescope (Fig. 18), showing great numbers of rounded craters presumably of earlier volcanic origin, ranges of mountains, large cracks or fissures, white streaks the nature of which is doubtful, and great grey plains which have been miscalled 'seas.' It is now known that *there is neither water nor an atmosphere on the moon*, hence life as we know it here cannot exist there. Knowing the distance of the moon, measurements of its apparent diameter have supplied information concerning its real diameter, which is 2163 miles; and this means that in volume, the earth is equal to 49 moons. The density of the



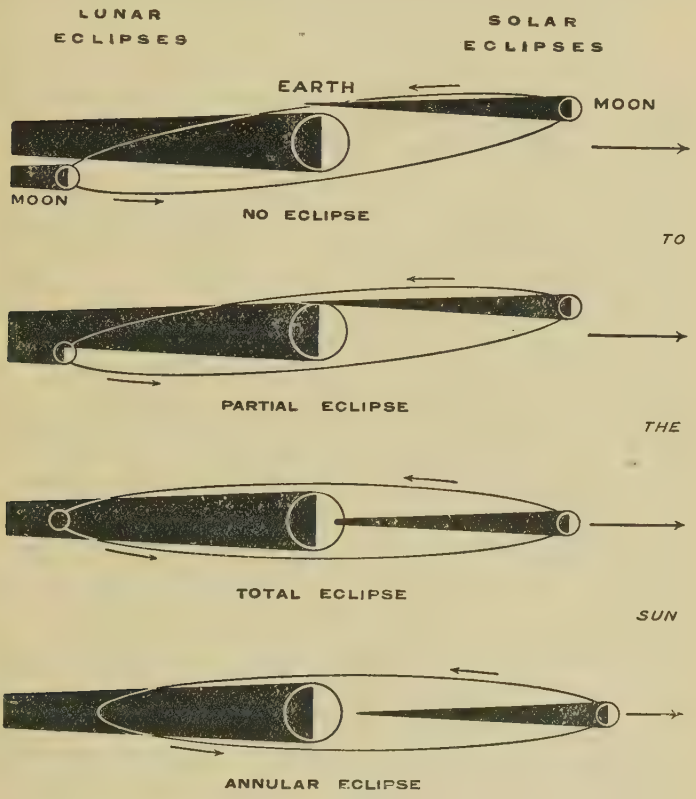
Drawn by Mr. Scriven Bolton.

FIG. 19.—THE MOTION AND PHASES OF THE MOON.

substances composing the moon is as a whole much less than that of the terrestrial rocks; it is on account of the smaller

size that objects on the moon weigh only $\frac{1}{6}$ of their weight upon the earth.

The moon exhibits **phases,** that is, its appearance is different at different parts of the lunar month (Fig. 19). It 'shines' by



Drawn by Mr. Scriven Bolton.

FIG. 20.—ECLIPSES OF THE SUN AND MOON.

light from the sun reflected by its surface, and as it journeys around the earth, it is clear from the diagram that we see different amounts of the illumined surface. It waxes as it proceeds from the position of *new* moon to that of *full* moon, then it decreases, or wanes. At the former position the dark

side of our satellite is facing us and we do not see it, but at full moon the whole of the illumined surface is visible. At positions between these extremes we see curved surfaces varying from thin crescents near the new moon to gibbous shapes towards full moon. At first and third quarter the illumined surface appears as a semi-circular area.

The orbit of the moon being inclined to that of the earth there are two points called **nodes** where these orbits intersect. On some occasions when the moon is at, or near, one of these nodes, the sun, moon and earth are all in the same straight line, so that an eclipse occurs. Since the moon must be in the plane of the earth's orbit for an eclipse to take place, that plane is also called the **plane of the ecliptic.** Should the moon come between the earth and the sun, the latter is eclipsed, the moon appearing as a dark object obscuring the sun (Fig. 20). Over a small portion of the earth's surface the moon is seen to blot out the sun completely, so that for people in that restricted area the eclipse is total, and features described in Chapter I may be observed. But over most of the earth the eclipse is partial, only a portion of the sun's face being covered by the moon. When the earth comes between the sun and the moon, the latter moves into the earth's shadow and is eclipsed, the eclipse being total if the whole of the moon passes into the region of the earth's shadow. If the orbits of the earth and of the moon were both in the same plane, an eclipse of the sun and of the moon would occur in each lunar month.

Although the moon is relatively small, it is so close to the earth that it exerts a strong gravitational pull which causes the oceanic waters to be heaped up at positions under the moon, and on the opposite side of the earth. This rise of water is called a **high tide** and as the earth rotates it brings various places in turn under the moon, so that these places experience high tide in succession. A more detailed explanation of tides is given in Section II, Chapter XIII.

CHAPTER III

THE EARTH'S CRUST

The relatively thin outer portion of the earth, the part upon which we live and into which we probe for minerals, is called the earth's **crust.** Though in the regions of latitude of Great Britain most of the earth's surface is covered with soil and vegetation, we may obtain glimpses of the crust in quarries, railway cuttings, river courses, and in the cliffs and beaches near the sea. In these places various kinds of rocks are visible. Any natural mass of substance large enough to form an appreciable part of the earth's crust is called a **rock,** whether it is hard like granite or soft like clay; for example, the mud in a river estuary is geologically as much a rock as the limestone cliffs which tower above the sea.

In some cases rocks consist of an aggregate of relatively small grains of different substances, and each of these substances is called a rock-forming **mineral.** Thus in the rock called **granite** we can distinguish glassy grains of **quartz,** pink crystals of **felspar,** and dark glistening flakes of **mica.** Quartz, felspar, and mica are the rock-forming minerals which together compose granite. Sometimes a single mineral species may occur in such large masses as to form a rock by itself. Quartz often forms as much as 95 per cent. of another rock called **sandstone,** and limestone usually consists almost wholly of a mineral known as **calcite.** Similarly **salt** is both a rock and a mineral. The term 'mineral' is often used in an economic sense to mean any kind of rock or mineral substance that is mined for commercial purposes. In most cases these commercial 'minerals' are more correctly termed rocks, since they occur in extensive masses. Slate, limestone, coal, and sand are examples.

Geology, the study of rocks and minerals, is of great importance to miners, civil engineers, surveyors, farmers, builders, and many others. *Man's relations with the earth's crust is probably the greatest factor of human existence.* Our food is dependent upon soils derived from decaying rocks ; fuels, metallic ores, building materials, and many other necessities must be mined ; estuaries must be cleared of river transported mud ; coasts must be protected against drifting shingle, and tunnels have to be drilled through great mountain ranges. The enormous influence of rocks and minerals upon daily life will be realised when it is understood that *the occupations of people, the density of population, the scenery, the means of transport, and to some extent the climate of any region depend chiefly upon the kind of rocks present in that particular area, and the way in which they are arranged.*

Rocks are of many different kinds, but in a broad general way it is possible to recognise three great groups according to the ways in which rocks have been produced. The **sedimentary** group includes all those rocks which have been formed by the accumulation of sediments generally deposited under the water of the sea or of lakes, but occasionally heaped up by wind, or other agency on the land. Most rocks in the world belong to this group ; certainly 85 per cent. of those in Great Britain are ancient sediments. The **igneous** group is composed of those rocks which have solidified from fusion due to heat, whether the solidification took place quickly at the earth's surface as in the case of **volcanic** rocks, or slowly and under great pressure at some place far below the surface of the ground, as in **plutonic** rocks. The third great division is the **metamorphic** group, which includes rocks that are produced by later alteration of either sedimentary or igneous rocks, the agents of such alteration being heat and pressure.

SEDIMENTARY ROCKS

The surface of the earth is slowly but constantly changing, particularly the relative arrangement of land and sea areas. The shallow seas around the British Islands, for example, have at times been land areas, and where land is now, in former times there was sea. Land conditions and marine deposition alternate

in cycles. Several seas have at different periods covered the site now occupied by Great Britain. Agents of destruction, chiefly wind, rain, and frost, are always breaking up the land into fine particles or sediments which are carried by rivers and then discharged into the seas around the coasts, or into lakes. The lighter particles, mud and clay, are carried farther out to sea than the heavier fragments of sand and gravel, which settle down nearer the shore. These sediments are slowly built up layer upon layer one above another, and eventually, as the sea recedes they will become dry, and form new land. The various layers are called **strata,** or beds of rock.

Nearly all sedimentary rocks exhibit this stratification, and it is obvious that the oldest strata are those which underlie the

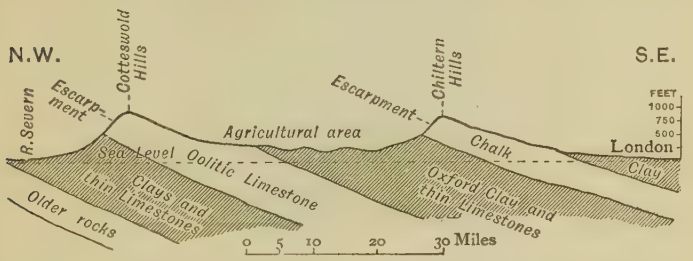


FIG. 21.—GEOLOGICAL SECTION OF THE COUNTRY BETWEEN THE SEVERN VALLEY AND LONDON.

others. *The relative ages of strata are thus determined by their order of superposition.* If the country from the Severn to London were cut open vertically by a huge knife, we should see a section exhibiting strata of ancient sediments gently dipping towards the east, so that the oldest appear at the surface in the Severn Valley and the youngest occur near London (Fig. 21). Since most seas contain living creatures, the sediments contain various animal remains, such as shells, corals, sea urchins, teeth of fish and other *hard* parts. Similarly, sediments accumulated in lakes and estuaries often contain plant remains. Such remains of former animals and plants now found, more or less mineralised, in sedimentary rocks are called **fossils.**

Now let us consider the chief types of sedimentary rocks, and their influence on daily life.

CONGLOMERATE

Many parts of the coast exhibit large tracks of beach composed of pebbles of various sizes rounded by mutual friction caused by the waves and tides. In the far distant future, this shingle may become cemented to a compact mass by sand or other substances deposited between the pebbles, and a rock called **conglomerate** will be formed. A conglomerate (Fig. 22) is a sure indication of the former existence of a beach, though the site may now be

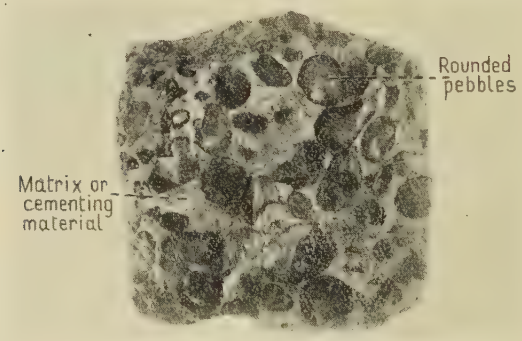


FIG. 22.—A PIECE OF CONGLOMERATE.
(Photo. by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.)

hundreds of miles inland. These pebble beds are fairly hard, resist weather well, and often form low ranges of hills. Nottingham Castle stands upon a conglomerate forming a distinct ridge which extends across that part of the town. As a rule these old beaches do not contain useful minerals, though some of them make good building material, such as that used in the construction of the main railway station at Bristol.

SANDSTONES

Just as modern shingle is succeeded seawards by wide stretches of sand, so conglomerates are usually associated with extensive layers of **sandstone.** Sand grains eventually become consolidated in much the same way as do pebble beds. Rain water

trickling through the mass of sand long after it has become land carries such substances as silica and oxide of iron into the spaces between the grains, and this welds the whole mass into a very compact firm rock. Sand itself consists of broken fragments of various minerals derived from the wear and tear of other rocks. Usually most of these fragments consist of the mineral called **quartz,** though many other minerals are often present in varying amounts. If these fragments are quite small, a fine grained sandstone is the result, but if they are relatively coarse a grit is produced and these are very useful as grindstones for sharpening steel, etc.

The older sandstones of the world are often thousands of feet thick, forming massive hills and generally fine scenery. The climate is usually bracing, but the absence of useful minerals apart from building stone causes these areas to be somewhat thinly populated. The chief occupations consist of sheep-rearing and catering for tourists, who visit the district to enjoy the scenery and the bracing air. Unlike limestone districts, sandstone areas have remarkably pure river water, and natural caverns are very uncommon. The Old Red Sandstone of Caithness in north-east Scotland is a massive formation of this kind, and such old sandstones must be distinguished from much more recent and less compact sandy rocks which build less impressive scenery, though they yield sand for glass making and other purposes. Younger, more friable sandstones of this kind occur in the south-east of England, and as these are porous they are valuable as a source of water which collects in them. Some sandstones containing few fossils appear to have been deposited on land by the agency of wind. They are old deserts.

CLAY

Since **clays** consist of minute rock particles which have been carried farther out to sea, the presence of such rocks indicate moderately deep water conditions at the time of deposit. Nearly all clays are of marine origin, though a few, such as the Wealden Clays forming the vales of Kent and Sussex, were formed in lakes or estuaries. The fossils, marine or freshwater species of shells, etc., found in a clay yield the evidence concerning its mode of

origin. Though it occurs as a definite bed sandwiched in between other strata, a clay does not usually exhibit stratification within itself ; it appears as a compact mass.

The utility of clays depends largely upon the fact that they occur in these compact and plastic masses. As this class of rock is soft, and only feebly resists the work of wind and rain, a typical clay district consists of either flat or gently undulating country, such as that in large portions of Oxfordshire, where a blue marine deposit known as Oxford Clay is found. A district of this type is almost entirely an agricultural one, and the population, though not great, is fairly evenly distributed in small market towns. Here and there clay is dug in brickyards and a certain amount of earthenware is made locally. Communication from one place to another is an easy matter compared with that in a hard sandstone area where roads and railways must use the river valleys.

Another typical clay region is found in Cheshire, but here great sheets of rock salt are interbedded with the clay. These valuable deposits of salt are really the dried-up floors of ancient salt lakes. Similarly, deposits of a pink or white mineral called **gypsum** are found in clays of the same age and kind. In its purer forms this substance is called **alabaster,** and being very soft, is easily worked into ornaments and bowls for electric lights. The cruder forms of gypsum are used for the manufacture of Plaster of Paris. Clays yielding salt and gypsum do not often contain fossils, as conditions in salt lakes are not very suitable for living creatures.

THE COAL MEASURES

A most important group of rocks called the **coal measures** consists of freshwater clays alternating with thin sandstones and coal seams. As the sandstones are only a few feet thick at a time, the resulting landscape is gently undulating. The Midland coalfields may be taken as typical examples. An earthy form of iron ore called **clay ironstone** occurs as lumps or nodules in the clays, and this together with the coal leads to such areas being the most densely populated though least attractive districts. Ironworks exist side by side with pit shafts, and clay pits are

numerous. Communications are easy, and there is usually a large network of railways.

Impressions of fern leaves, etc., may sometimes be seen in a piece of coal indicating that this mineral is really fossilised plant remains. Each seam of coal represents so much vegetable matter, reed-like trees and gigantic ferns, which was buried by silt discharged into lakes, millions of years ago. Forests sank beneath the water and were buried by sediments which formed soils for new forests to arise, and these in their turns were submerged and covered. Freshwater species of shells found in the coal measures prove the lacustrine origin of these rocks. In other cases it appears that leaves, twigs, roots, etc., were drifted down rivers into the mud of estuaries and there covered. Vegetation thus buried gradually decomposes, losing various gaseous substances and the residue becomes the hard stony material we call coal.

Some rocks are composed of matter very similar to that in a clay, but this matter is arranged in very thin layers or laminae, several of them in a bed an inch thick. This kind of rock is called a **shale,** and in some of the Scottish examples vegetable remains in the shale have decomposed with the formation of oil which is obtained by distillation.

LIMESTONES

In deeper water, still more remote from land, the shells and other hard parts of marine animals accumulate on the sea floor as these creatures die. In the course of time huge shell banks and other heaps of organic remains become consolidated to a firm pale grey rock known as **limestone,** since the organic remains are composed of carbonate of lime or calcite. Most limestones are of a marine origin though a few have been formed in lakes as shown by the nature of their fossil contents—freshwater snails and pond mussels. A piece of marine limestone that has been exposed to the action of the weather for a long time generally shows the various structures of the remains composing the rock. Rod-like bodies termed encrinites are frequently present in great numbers, so may be corals and shells (Fig. 23). Some of the structures are so minute that they can be seen only by the aid

of a microscope. At the present day a cream-coloured mud dredged up from the floor of the Atlantic ocean is composed mainly of similar very minute shells. This **Globigerina ooze,** as it is called, after the species of shell known as *Globigerina*, is in many ways similar to the chalk that forms hills in the south-east of England and elsewhere.

Though chalk is soft, most limestones are very hard, and when of great thickness they form rugged mountain scenery with deep valleys called **dales.** Percolating rain dissolves the rock in

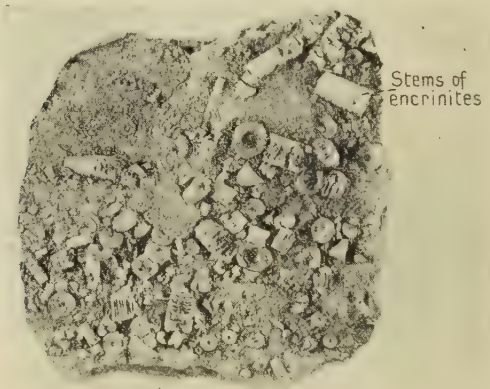


FIG. 23.—A PIECE OF WEATHERED LIMESTONE.
Photo. by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.

places, so that the hills frequently contain many natural caverns often having pillar-like **stalactites,** while many streams disappear underground and come to the surface as springs in other parts of the district. Water in limestone areas is very hard and must be softened before it can be used for steam engines and some domestic purposes.

These massive limestone districts are usually bleak and thinly populated, but contain important tourist centres such as Matlock and Buxton in the Peak district. A certain amount of agriculture is carried on, chiefly the rearing of sheep, which can exist on the short grass clothing the hill slopes. The limestone

is quarried in places for the production of lime used in agriculture and other industries, while limestone itself is transported for use as a flux in the smelting of iron ore, etc. The thick ' Carboniferous Limestone ' is responsible for the scenery of the Pennine Range (Fig. 26), the Peak District (Fig. 24), the Avon Gorge at Bristol, the Mendip Hills, and many parts of Wales.

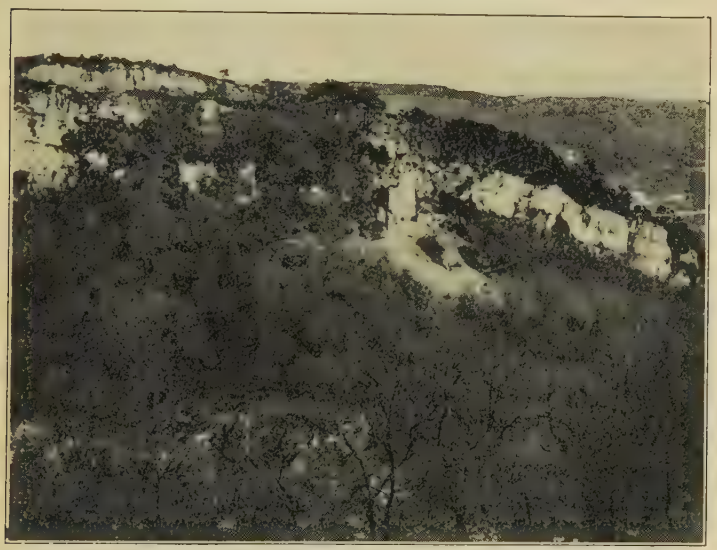


FIG. 24.—TYPICAL LIMESTONE SCENERY,
MATLOCK DALE, DERBYSHIRE.
(By courtesy of the Director, Geological Survey.)

Communications in these districts are difficult and railways must take advantage of the river valleys. A geological map, that is, one which shows the kinds of rock present, is given in Fig. 25 of the country around Derby, and it is possible from this to form a mental picture of the scenery and of the occupations of the people living in different parts of the region.

CRUSTAL ARCHITECTURE

Though the kind of rock present in an area is of prime importance, the arrangement of rocks is a factor in both the

evolution of scenery and the development of human activities. In Great Britain the most usual arrangement of sedimentary rocks

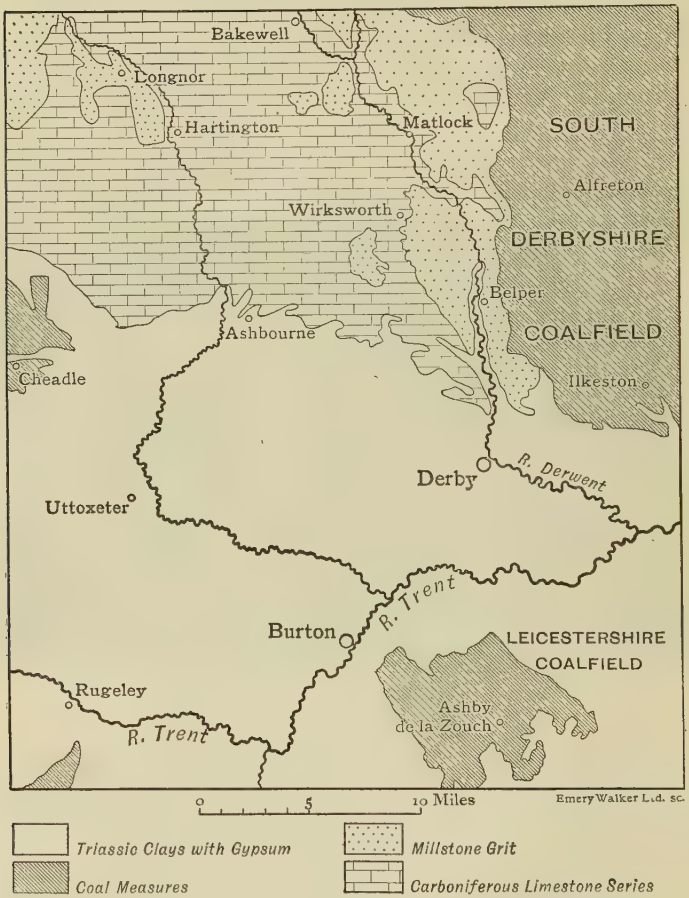


FIG. 25.—GEOLOGICAL MAP OF THE DISTRICT AROUND DERBY.

consists of very gently inclined strata such as those extending from the Severn to London. This piece of country has already been illustrated by a geological section or drawing which shows how the strata would appear if the ground were cut open verti-

cally (Fig. 21). Geologists in walking over the country collect sufficient evidence from quarries, railway cuttings, etc., to enable them to obtain a correct interpretation of rock arrangements. Let us examine, without too much detail, the section from the Severn to London.

The oldest of these particular strata consist of relatively soft thin limestone and clays forming the Severn Valley. Proceeding eastwards a traveller soon comes to the steep face of the Cotteswold Hills, a fine range due to a harder yellow limestone called **oolite,** because it is formed largely of minute egg-like grains of limestone. A piece of oolitic limestone resembles in appearance the hard roe of a fish. This rock, which is more massive than the other oolites, forms a high ridge extending many miles across the country towards the north-east, and such a ridge due to this arrangement is called an **escarpment.** Nearer London another less massive escarpment of chalk forms the Chiltern Hills, which like the Cotteswolds form a sheep-rearing district.

The agricultural country between the two escarpments is composed mainly of the Oxford Clay and thin limestones not massive enough to form prominent ranges of hills. These rocks including the clays are for convenience classified as ' oolites,' though oolitic structure is found only in the limestones. Around London the clay known as **London Clay** together with some sandy beds and gravels form a flat area which would be simply an agricultural district if it were not for London, a city of enormous growth due to its magnificent position. Farther to the west of the Severn, rocks still older than the oolites come to the surface in Herefordshire and Wales, and it is interesting to note that, since the Coal Measures are older than the oolites, most of the great manufacturing districts of England are situated to the west of the oolite escarpment.

In England, strata are usually gently inclined, and though they may appear horizontal in a quarry, they are found to dip slightly when traced over many miles of country. If traced far enough they may sometimes be found to change their direction of dip owing to the existence of a folded arrangement.

As the earth cooled, the rocks of the crust, endeavouring to fit themselves to a contracting mass, were subjected to strains and

stresses which caused some to be thrown up into folds in various places and at different times. In this way most of the great mountain ranges of the world, such as the Alps and the Himalayas, have been formed. Geologically, these great ranges are young compared with our own Pennines.

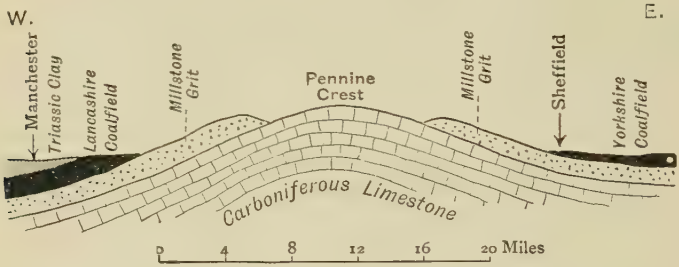


FIG. 26.—THE PENNINE ANTICLINE.

If we study the country between Manchester and Sheffield (Fig. 26), we find that the strata rise and fall in a simple fold called an **anticline** because the beds of rock dip away from the crest of the Pennines both towards the west and towards the east. The chief effects of this arrangement are obvious. The hard limestone has been carried upwards, intensifying the height and

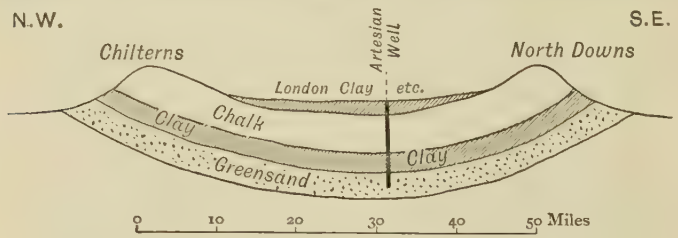


FIG. 27.—THE SYNCLINAL FOLD OF THE LONDON BASIN.

bleakness of these highlands. The Coal Measures have been divided into two widely separated coalfields, that of South Lancashire on one side, and that of Yorkshire on the other. The Pennine fold forms a sufficient barrier to most of the rain coming from the west, so that the climate of Lancashire is very different from that of Yorkshire.

Anticlines are often associated with folds of the opposite kind

called **synclines.** In this arrangement the beds of rock dip from both sides downwards towards the central part of the fold. The London Basin is a fold of this type, and a section from the Chilterns in the north to the North Downs in the south of the area is given in Fig. 27, so that the repetition of the hills can be understood. Two chalk escarpments have been formed, and the country between them is composed of London Clay and various gravels. Both the chalk and the greensand below it are excellent holders of water so that borings in the lower parts of

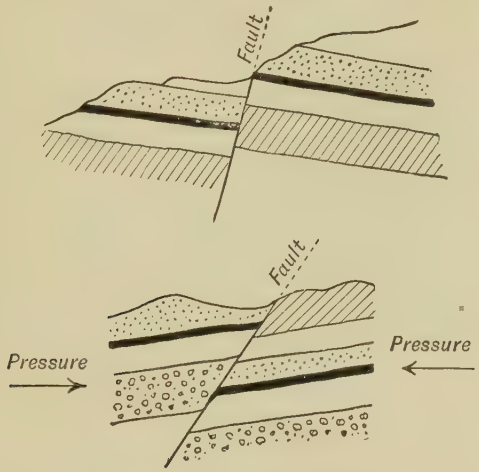


FIG. 28.—GEOLOGICAL SECTIONS ILLUSTRATING FAULTS.
THE UPPER FIGURE REPRESENTS A NORMAL FAULT; THE LOWER FIGURE A REVERSED FAULT.

the London Basin cause water to rise to the surface. Such **artesian wells** operate because water in the rocks up in the hills is at a higher level than that in the boring.

In mountain systems such as the Jura and the Alps, anticlines and synclines follow each other in succession, and though it is not always the case, the synclines are usually valleys while the anticlines are the crest of the mountains.

Movements of the earth's crust are also responsible for fractures called **faults** which may or may not be associated with folding. The great majority of faults are due to gravity, a part of the

ground having fallen down relative to the remaining parts as shown in the upper figure of Fig. 28. These are called **normal** faults, and should a large piece of country collapse between roughly parallel faults of this kind a **rift valley** is produced. The central lowland area of Scotland is such a rift valley where Coal Measures have been let down between hard crystalline highlands to the north and slate uplands to the south. The Valley of the Jordan in Palestine is another example.

The converse of a rift valley is a **horst,** a mass of rocks left standing up when the country around it has collapsed. Some of the mountains of Central Europe are of this type. If pressure from the sides causes a mass of rocks to be pushed up above others, as shown in the lower section in Fig. 28, the fault is said to be **reversed,** and is sometimes termed an **overthrust.** The structure of the Scottish Highlands is complicated by a great number of gigantic overthrusts sometimes involving miles of country. Faults on a large scale modify scenery, and on a smaller scale have important influence on mining operations. Solutions and heated vapours have, in former times, carried mineral substances, such as lead ore, into cracks and cavities caused by faults, which thus become important mineral veins. A coal seam ceases suddenly against a fault, and by studying the direction of slope of the fault, a miner can tell whether he must go up or down to recover that particular seam.

THE GEOLOGICAL RECORD

The vast mass of sedimentary rocks in the world forms a great natural ' book ' containing the record of life on our planet since the fossilized remains of animals and plants found in these rocks show us quite clearly the kinds of creatures which inhabited the earth at various periods. The complete book from those early pages known as the **Pre-Cambrian rocks** to the present time contains a great collection of old sediments, which, if taken together and in their correct order, forms a volume many scores of miles in thickness. All these pages do not occur in one country, however. Even in the British Isles, where rocks of most geological ages are represented, there are some important gaps. Generally, if a set of strata of a certain age are missing

in one country they may be found in another. This means that while one area was a land surface undergoing slow destruction by the weather, another area was covered by sea where sediments were being deposited. Some rocks were deposited under conditions very unsuited to living creatures and therefore contain few or no fossils, and in other cases strata which were originally fossiliferous have been removed by denudation or altered by heat and pressure with consequent destruction of organic structures which may have been present. These causes produce a few gaps in the history of former living things, so that *the geological record is said to be imperfect.*

This imperfection is relatively slight, however, and the study of fossils, or **palaeontology,** enables us to form a fairly accurate conception of the development of life upon the earth. The general development or evolution of living creatures has proceeded from the simple to the complex. In the earlier fossiliferous rocks termed **Palaeozoic,** we find only fossils of simple animals including shells, corals, sponges, trilobites, and early types of fish and reptiles. The trilobites so called because their bodies were tri-lobed, were something like the modern wood lice and are occasionally found in the rolled up condition (Fig. 29). Rocks containing trilobites occur chiefly in Wales. The Coal Measures containing a rich fossil flora are also of Palaeozoic age.

FIG. 29.—A TRILOBITE.
Photo. by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.

The country between the Severn and the Chilterns is composed of Middle Period or **Mesozoic sediments.** Fossils found in these are more advanced than those occurring in the Palaeozoic formations. Besides shells, sea urchins, corals, and ammonites, the first birds and mammals made their appearance. But this

period was essentially the age of reptiles, some of them being of huge size and known as Dinosaurs, while others, the Pterodactyls, were able to fly. The ammonites (Fig. 30) were a group of molluscs related to cuttle fish and inhabited coiled shells, though these are found uncoiled in the later stages of the history of the group, and it died out in the chalk period. The remaining younger sediments were laid down in the **Tertiary** or **Cainozoic Period.** During tertiary times the animals and plants slowly

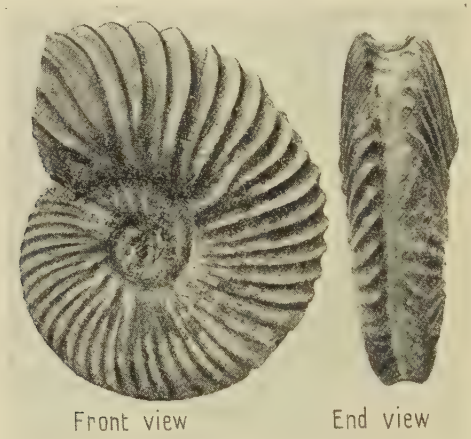


FIG. 30.—AN AMMONITE.
(*Photo. by Dr. L. F. Spath.*)

became more and more like those living to-day, and towards the end of this period man himself was an inhabitant of the earth.

The whole time represented by all of the fossilferous strata taken together is probably about 600 million years.

Apart from questions of organic evolution, fossils supply information concerning earlier geographical conditions. As we have seen, the former existence of seas, lakes, and desert areas are indicated by fossils or their absence. The presence of arctic shells or of tropical plants yield definite information concerning the climate existing at the time when rocks containing such fossils were deposited. Certain strata often contain very

characteristic fossils which are therefore of use in determining the age of rocks when the order of superposition may not be seen easily. By means of these **zone fossils,** as they are termed, rocks in one country may be correlated with those in another. Zone fossils are of particular value to the prospector since they indicate the presence of certain strata that may contain useful minerals.

IGNEOUS AND METAMORPHIC ROCKS

The solid materials ejected from a volcano fall upon the ground or upon sediments being deposited near the coast. Volcanoes are usually situated near the sea, and in bygone times vast sheets of **lava** have been poured over the sea floor and afterwards covered with more sediment. In this way old lava streams and beds of fragments or ' ash ' have become *interbedded* with ordinary sedimentary strata, and with them may form escarpments, anticlines, etc. Sometimes old volcanic craters and channels are visible, as in Derbyshire, but frequently the actual vents are either concealed under later rocks or have been destroyed by **weathering.** In these cases sheets of interbedded lava remain as evidence of former vulcanism. Old lavas of great thickness are thus found as beds of rock between other strata in Wales, the Lake District, the Midlands, and in Scotland. In the formation of rugged mountain districts supporting a thin population, volcanic rocks resemble the harder limestones and sandstones. The scenery is often magnificent, and results in a ' tourist industry.'

Snowdon is a mass of lava and volcanic ash some 3000 feet thick poured from great vents hundreds of millions of years ago. By far the most ancient volcanic rocks found in Britain, and indeed in the world, are those found in Charnwood Forest in Leicestershire, and at the Wrekin in Shropshire. These take us back into the mists of antiquity to a period so remote that few if any living creatures had then made an appearance on the earth. In north-eastern Ireland occurs a plateau composed of lavas of very different age and type. These **basalts** were discharged from huge fissures miles in length, and there were several different eruptions at different times, though all of them occurred within

the Tertiary Period. Basaltic plateaux of a similar type are found in the Idaho region of North America. A pronounced feature of this class of rock is the formation of columns as the mass cools. The Giant's Causeway in Northern Ireland is a fine example.

Volcanic rocks vary considerably in appearance, some being light pink or green, while others are grey or black. They are usually fine grained, and some show great numbers of pores and cavities due to the escape of steam as the material cooled. If we

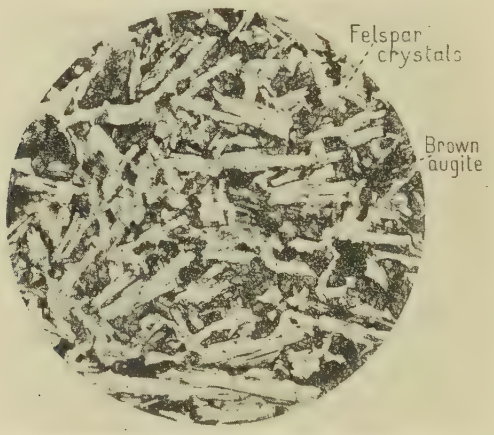


FIG. 31.—A THIN SECTION OF BASALT AS SEEN UNDER A MICROSCOPE.

(Photomicro by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.)

examine a thin slice of black lava or basalt with a microscope (Fig. 31), we find that it is composed of white elongated crystals of felspar and brown crystals of a mineral called **augite.** The crystals of felspar and augite are well formed due to the absence of any other rocks pressing upon them as the molten mass cooled. Such well-formed crystals are said to be **idiomorphic,** and are characteristic of most volcanic rocks. Both the felspar and the augite are present in two distinct sizes, one set of each mineral being much larger than the other crystals, the latter forming what

is called the **ground mass.** The larger crystals were already formed when the lava was ejected, and the smaller crystals of the ground mass were formed as the rock solidified. *This differentiation into two distinct generations of crystals is another characteristic of volcanic rocks.*

Many useful substances are obtained from volcanic material. Basalt makes an excellent road 'metal' and is extensively quarried for that purpose. Owing to the chemical instability of the felspar, some basalts decay under the influence of the weather and form brown or red clays called **bauxite** which are very valuable sources of the metal aluminium. Pumice is a light coloured very porous lava used as an abrasive, and a dark volcanic natural glass called **obsidian** is used for knife handles, etc.

The **Plutonic rocks,** named after Pluto, the god of the underworld of the Ancients, are crystalline masses, such as granite, which solidify some distance below the surface of the earth. They become visible at the surface because rocks above them are removed by prolonged 'weathering.' One of the best examples in Britain is Dartmoor in South Devon. This picturesque and thinly populated moorland is composed of granite which has been thrust into ordinary strata, slates and grits, of middle Palaeozoic age. Since plutonic rocks are thrust as irregular masses into other rocks they are said to be **intrusive.** Intrusions have occurred at various geological periods, consequently intrusive rocks are of different ages. Smaller offshoots of the granite or other plutonic rock frequently extend along the bedding planes of the invaded strata and are called **sills.** Offshoots thrust into cracks and fissures more or less at right angles to the stratification are known as **dykes.**

The conditions under which a plutonic mass solidifies are quite different from those influencing the consolidation of a lava flow at the surface. A piece of granite, which may be regarded as typical, exhibits crystals of quartz, mica, and felspar large enough to be seen by the unaided eye, and in some cases, such as Shap granite from Westmorland (Fig. 32), crystals of red felspar more than an inch in length are present. This particular rock is much used for the fronts of shops and banks.

Though the crystals in plutonic rocks are larger than those in a lava, they are very imperfectly shaped owing to the pressure of superincumbent rocks at the time of solidification. They are not idiomorphic. In dykes and sills the minerals are usually shaped better as these smaller masses cool more quickly and frequently under less pressure. The microstructure of a dyke rock is somewhat similar to that of a lava. Plutonic rocks are useful mainly as building stones.

The **felspar** in a granite is a different species from that in a basalt, but it similarly decays forming a white clay called **kaolin**

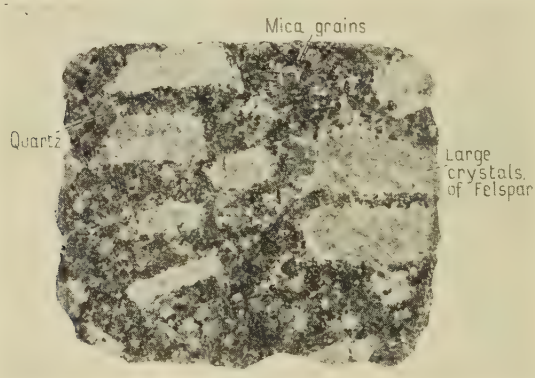


Fig. 32.—A Piece of Shap Granite.
(*Photo by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.*)

which is the best material for the manufacture of good china ware Kaolin is found extensively in South Cornwall and in consequence an important local industry is the manufacture of china.

Metamorphic rocks are produced by alteration of *any* class of rock, though there is a relation between the original material and the metamorphic product. Thus granites are converted to a crystalline rock called **gneiss,** clays and shales become **schists** and **slates,** sandstones become **quartzites,** and limestones are converted to **marble** with the destruction of any fossil structures which

may have been present. In a general way, two modes of alteration may be recognised. A heated intrusive mass such as granite bakes the surrounding rocks and produces *thermal* metamorphism. In the other process, huge masses of rock are pushed bodily over others and the resulting heat and pressure produce *regional* or *dynamic* metamorphism. In either case the results are similar ; granites become gneiss, clays are altered to slates, and so on.

The chief result of metamorphic changes is the production of new structures, one of the more valuable being the **cleavage** of slate which enables it to be split into remarkably smooth thin slabs. This quality together with the absence of porosity makes this rock a most useful material for roofing, cisterns, etc. Slates occur in the older Palaeozoic rocks, the best being worked at Penrhyn and Blaenau Festiniog in North Wales. Another new structure found in gneiss and schist is a stringy or banded arrangement of the minerals called **foliation.** Thus a piece of schist is composed of strings or folia of mica alternating with folia of quartz grains. If felspar is also present, the rock is a gneiss. Both schists and gneisses form bleak mountain country such as that in the Highlands of Scotland and of Donegal.

CHAPTER IV

THE CHANGING FACE OF THE EARTH

RESTLESSNESS is a characteristic feature of Nature. In both the organic world of living things and in the inorganic portion of the universe, one thing which really appears everlasting is the Law of Change. The earth's crust affords a magnificent and varied example of this rule. Though the great hollow of the Pacific Ocean may have been subjected to relatively slight alterations, the continental masses have been considerably modified, ancient lands having foundered beneath the sea. The lost continent of Atlantis in the North Atlantic is not altogether a myth, and the string of islands known as the Antilles or West Indies in the Caribbean Sea now represent the sunken land mass which may be termed *Antillia*.

As we have seen in the previous chapter, the British Islands have been engulfed by the sea many times, and at another period, not so long ago geologically, they were united with Western Europe, when the site of the North Sea was a land area. New land is slowly being constructed while old land surfaces are being gradually but surely destroyed by wind, rain, ice, and other agents of destruction.

MOVEMENTS OF THE EARTH'S CRUST

Enormous quantities of rock particles are taken by rivers to the sea where they accumulate on the submerged platform called the **continental shelf.** Although most rocks in themselves appear rigid, the earth's crust as a whole is by no means rigid In time the countless thousands of tons of rock material collected upon the continental shelf weigh it down (Fig. 33).

The sea floor sinks and the adjacent land rises correspondingly. This game of see-saw played by the weighted sea floor and the neighbouring land is termed **isostasy** or **isostatic balance,** and explains why the higher land is not worn down to a low level at the rate it would be if it were merely a question of the removal of rock matter.

The borders of the continents are the most unstable regions of the earth, and this instability produces large fractures with resulting **earthquakes** and causes volcanic phenomena. The lands bordering the Pacific Ocean on both the Asiatic and the

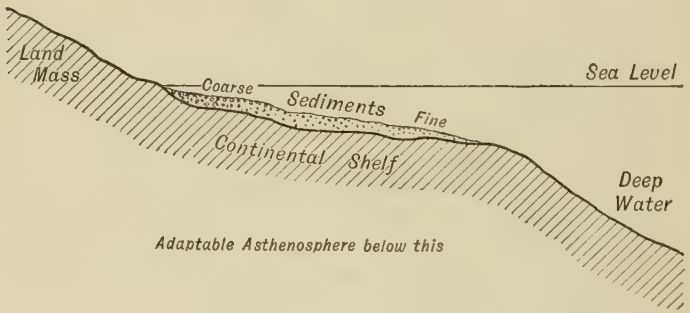


FIG. 33.—ISOSTATIC BALANCE,
AND THE FORMATION OF SEDIMENTS UPON THE CONTINENTAL SHELF.

American sides are regions most susceptible to disastrous earth tremors, as evidenced by recent seismic occurrences in Japan, and calamities in California and Chile. Another line of crustal weakness extends through the region of geologically young folded mountains from the Alps to the Himalaya. The most unstable portion of Europe is in southern Italy where the Apennines swing round toward the Atlas Mountains of North Africa.

Though a sinking continental shelf may account for most earthquakes, other possible causes include the tidal forces which attract the solid ground as well as the oceanic waters, the collapse of caverns, the slipping of large land masses, and volcanic disturbances, though it should be clearly understood that most great earthquakes occur unaccompanied by any vulcanism. Any of these causes may produce a kind of wave-motion which, commencing at the **focus** or place where the cause

operates, proceeds rapidly in all directions through the surrounding rocks. Just as a ripple travels through water, so a complex type of wave motion traverses rocks. There are some important differences however. Whereas water waves may rise and fall several feet, particles of rock usually vibrate through only a fraction of an inch, and though wave motion in water travels slowly, that in rocks proceed at rates measured in thousands of feet per second. If a severe earthquake occurs in New Zealand, delicate instruments called **seismographs** record it in England about twenty minutes later. The earthquake wave travels right through the earth, a distance of nearly 8000 miles, in that time.

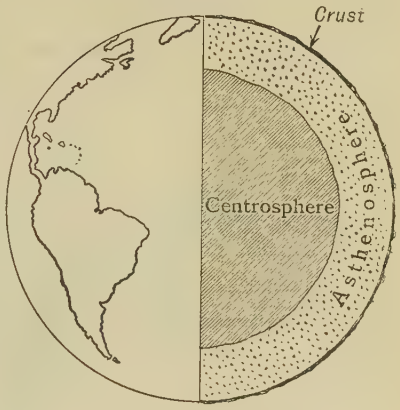


FIG. 34.—SECTION THROUGH THE EARTH.

Wave motions travel comparatively slowly through liquids, and modern researches on the speed of earthquake waves have led to the conclusion that *the earth is solid throughout*, and that the great central portion is composed of some substance, possibly iron, as rigid as steel. An earthquake originates three different kinds of waves and at least one of these could not pass through the earth if the centre or core were liquid.

It is now known that between the great iron **centrosphere** and the thin unstable crust is a shell some hundreds of miles in thickness composed of a solid though movable material which adapts itself to crustal movements. This shell of adaptable substance has been called the **asthenosphere,** a term which signifies weakness, since the material is more or less plastic and not rigid (Fig. 34). The continental shelf sinks and the land near it rises because of this adaptability of the asthenosphere.

In relation to human life and property earthquakes are wholly an evil, but those which occurred in past ages have left us a

legacy of fissures and faults along which sometimes valuable metallic ores have been retained for our use. In other cases, as that of Central Scotland, gigantic disturbances have let down and thereby preserved coal bearing rocks or other strata of economic value.

VOLCANIC ACTION

If the earth is solid throughout, how is it that molten rock is ejected from volcanic vents? Below the surface of the ground the temperature of the rocks rises rapidly. Observations made in mines and deep borings show that there is an average rise of

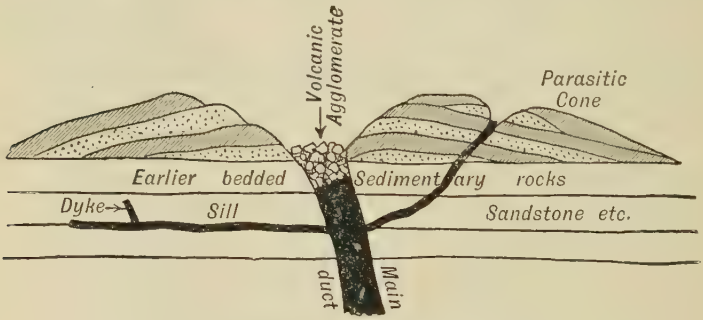


FIG. 35.—SECTION THROUGH A VOLCANO.

temperature of 1° F. for every 60 feet of descent. At a depth of a few miles the temperature must be high enough to melt the rock material in *normal* circumstances, but owing to the pressure of the rocks above, the material cannot melt unless the pressure is relieved by fracture or other cause. When such relief of pressure occurs, the superheated rocks become molten and are forced upwards along fissures or channels to the surface (Fig. 35).

Volcanoes are distributed usually in lines but occasionally in groups along the weak unstable portions of the earth's crust, and, as we have seen, these regions are mainly the borders of the continents, particularly the land fringing the Pacific Ocean. The motive power which is mainly responsible for volcanic action is **steam** formed from water percolating through rocks and coming in contact with the heated mass below.

There are two distinct types of vulcanism. In a normal volcano, matter is ejected from one or more rounded vents or craters, while in **fissure eruptions** great quantities of molten rock flow more or less quietly from long cracks or fissures in the ground. The huge sheets of basalt in Northern Ireland have been produced in this way, and fairly modern eruptions of the fissure type have occurred in Iceland, where the earlier landscape has been blotted out as if molten sealing wax had been poured over the country.

In the usual eruption of a normal volcano there are generally three successive phases. At first the materials ejected are gaseous, by far the greater portion being steam which ascends several miles into the air, becomes cooled and condenses with the production of rain. The second phase, known as the 'ash stage,' is characterised by the bursting of huge lava bubbles within the crater. The explosive force hurls fragments of all sizes into the air. The larger fragments fall back around the vent and help to build up the usual volcanic cone, while the finer dust particles mingle with descending rain and form a mobile volcanic mud. It was volcanic mud of this type which overwhelmed the town of Herculaneum near the foot of Vesuvius in the classic eruption of the year A.D. 79, while at the same time the more distant Pompeii was covered with hot 'ashes.' The third and final phase consists of molten lava which rises above the lip of the crater and flows quietly down the mountain slopes. If the material is of the more viscous type, its progress is slow, but in the case of the more mobile fluid lavas, such as basalt, the rate of travel may be equal to that of an express train.

It follows from this that the more viscous lavas build steep cones, whereas the basaltic kind build relatively low dome-like structures when such material is ejected from normal craters and not from fissures. Though a normal eruption exhibits the three successive phases, it sometimes happens that the lava stage may not occur, the force having spent itself too soon. This was the case in the great eruption of Vesuvius mentioned above, though disastrous flows of lava have been ejected from that volcano in more recent times. Certain abnormal eruptions are characterised by great explosive violence during the ash stage resulting

in disastrous clouds of minute incandescent dust which sweep down the mountain side devastating all in front of them. The destruction of St. Pierre in the West Indies in the year 1908 was due to such a dust avalanche. The island of Krakatoa in the Sunda Strait blew up in the year 1883, scattering fragments and dust which produced darkness for a distance of 150 miles. Windows were broken at Batavia, a town a hundred miles away.

Some volcanoes may remain quiet for centuries and then break out again. Old volcanoes which have never been known to erupt are said to be extinct. In former times, particularly during the Palaeozoic period, Great Britain has been the scene of great volcanic outbursts. In Derbyshire and other places actual vents can be seen filled with lumps of lava which fell back into the old craters. Along the coast of Fifeshire occur numerous ancient volcanoes the inner structures of which have been exposed by the destructive action of the sea, and more can be learned from these old dissected vents than from a visit to a modern volcano, the internal workings of which are hidden from view.

Though much destruction and loss of life has been caused by great eruptions, man benefits in many ways from volcanic activity. The magnificent scenery produced by ancient lavas and the uses of pumice, obsidian, and road metal have already been noted. Many volcanic rocks, particularly basalts, form very rich soils, and some basalts decay forming a clay which is the world's chief source of aluminium. The interaction of sulphurous and other vapours in the neighbourhood of some craters and vents yields extensive incrustations of sulphur. Vapours issuing from the ground in regions such as Tuscany, where vulcanism is in its dying stage, yield boracic acid and natural high pressure steam which is actually being used to generate electricity at the volcanic power station of Larderello. (Fig. 36). It should be noted that natural inflamable gas and oil wells are not volcanic, since steam is not the motive power. In this case decomposing vegetable or animal matter is regarded as the origin.

Like the natural vapour springs known as **fumaroles** and **soffioni** of Tuscany, water volcanoes or **geysers** occurring in

the Yellowstone Park District of North America and in New Zealand are symptoms of the approaching extinction of vulcan-

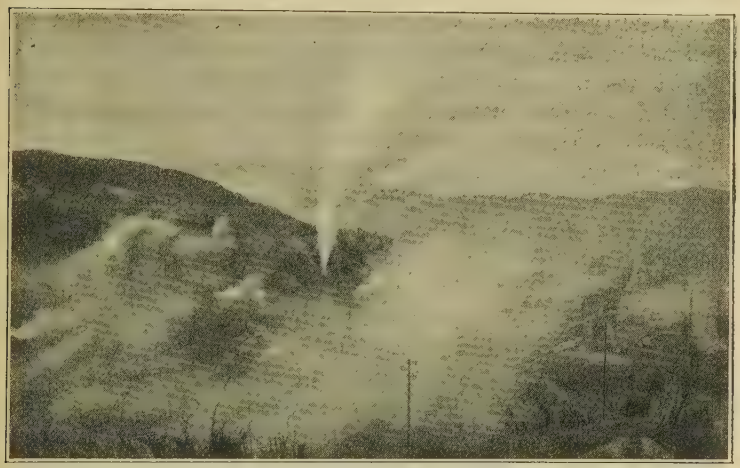


FIG. 36.—GENERAL VIEW OF THE STEAM FIELD OF LARDERELLO.

icity in a region. Eventually even these cease, and a district formerly a theatre of mighty convulsions becomes stable; its volcanic history is complete.

CHANGES PRODUCED BY RIVERS

Though the face of the earth has been much changed by earthquakes and volcanoes along definite lines, most countries in nearly all latitudes are subjected to persistent modification by wind, sunshine, frost, rain, ice, and the sea, which function sometimes as destructive agents, at other times in a constructive capacity. The most widespread of these agents is **rain**, which, collecting as streams that unite to form rivers, wears away rocks, transports the particles, and finally deposits them in another place. In a typical river course three distinct portions are recognisable. In the hill country where the river commences its journey the slope is steep, the velocity of the water is consequently great and its work is mainly of a destructive character. Stones often of

considerable size are swept forward with much consequent wear and tear, including the formation of rounded **pot holes** excavated by stones whirled round in eddies. When a hard bed of rock above softer material is encountered a waterfall is the result, and as the rock breaks away the fall slowly recedes upstream. This upper part of a river course is called the **torrential tract,** and it is this part of the river which is utilised to give water power for the generation of electricity, etc.

The middle portion of a river course where it flows more slowly through a wider gently sloping valley is known as the **valley tract.** The work of the river is here partly destructive and partly constructive since much of the coarser transported material is deposited owing to the reduced velocity. Another result of reduced speed is the turning aside of the waters by harder rocks encountered along the course. The river in taking the path of least resistance often winds about in curves called **meanders.** Sometimes the meanderings are so tortuous that two turns may meet and coalesce with the result that the detached curved remnant forms an **ox bow lake.** At each turn of the river the velocity is greater on the outer or convex side so that the ground on this side is worn away farther while sediments are deposited on the other concave side. The gently sloping valley tract usually provides good pastures, and in the absence of valuable minerals constitutes an agricultural area.

In the lower part of the river course or **plain tract** the speed is reduced to a minimum, the sediments settle down and construct a flat alluvial region. In the case of large rivers such as the Nile, the water divides into distributaries which flow past great patches of deposited **alluvium,** as such fine transported rock material is called, and in this way a **delta** is produced. *These large alluvial tracts form the most fertile soil in the world.* Prolonged silting in this way produces enormous fertile plains such as that of Lombardy in Northern Italy. In England the rivers around the Wash have produced a fairly large alluvial plain, the Fen District, which on account of the soil and a moderate rainfall is the finest wheat growing area in the country.

By depositing its own silt, a great river like the Hoang Ho in

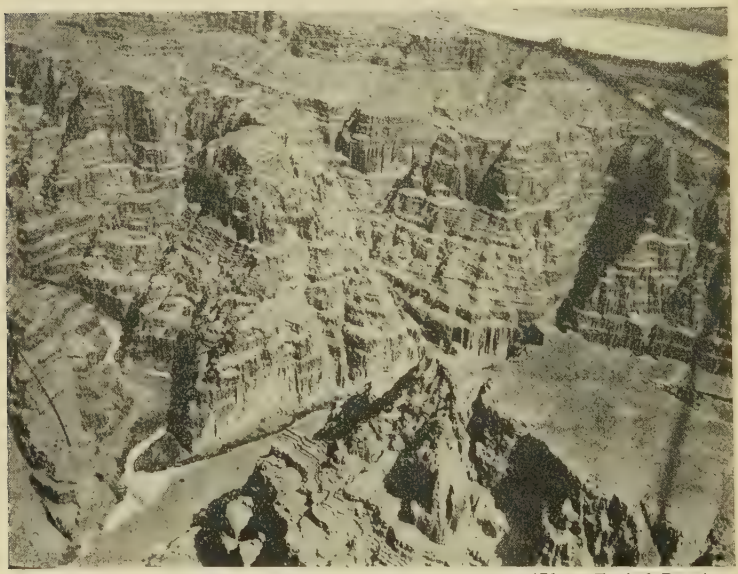
China builds up a natural embankment or **levée** on which the water continues to flow. At times, as in Mississippi floods, the pressure breaks down this embankment with disastrous results to both human life and property. The necessity for the clearance of alluvium from estuaries by dredging affords another example of the fact that deposits of this nature, so valuable in agriculture, may be a nuisance in other ways. The decline of ports such as Boston in Lincolnshire is due to silting combined with the increased tonnage of ships. One of the chief difficulties in connection with the Severn tidal power scheme is that due to the enormous quantities of silt brought down by that river. In the plain tract of the Po in Italy, Adria and other ancient ports have been completely separated from the Adriatic Sea by silt transported from the Alps.

The transport of silt and pebbles is work of a mechanical nature, but rivers frequently perform work of a chemical kind as well. This is particularly the case where the water flows over limestones, which are in part dissolved and thus taken to the sea in solution. A striking example of Nature's providence is afforded by the existence of huge beds of *soluble* nitrates in the *rainless* districts of Northern Chile.

Any form of rock destruction whether mechanical or chemical is called **erosion** or **denudation**. A special type of mechanical erosion may be considered here. It sometimes happens that rivers derived from snow on distant mountains flow through a rainless area. Such rivers continue to cut their beds downwards as a saw cuts through wood. There is no rain to develop side streams and the result is a deep valley called a **canyon** such as the magnificent example carved by the Colorado River in North America (Fig. 37).

One of the greatest benefits which river action has conferred on mankind consists of the means of communication through hilly or mountainous countries. The head waters at the upper end of a river are constantly cutting the valley backwards, so that eventually one valley may cut back into another on the opposite side of the mountains. In this way a **pass** is produced, and a line of communication from one side of the mountains to the other is made possible. The importance of river valleys in

relation to railway routes and roads will be understood better by a brief consideration of the evolution of a drainage area such as the small but classic river system draining the Weald, in south-east England (Fig. 38). At the end of Mesozoic times a long oval chalk-covered land emerged from the Cretaceous Sea. The longer axis of this mass extended roughly from west to east, so that the rain which fell drained chiefly towards the north and



(*Photo. Topical Press.*)

FIG. 37.—GRAND CANYON, COLORADO, AS SEEN FROM THE AIR.

to the south. Such modern Wealden rivers as the Wey, Mole, and Medway flowing towards the Thames, and the Sussex Ouse, Arun, and Adur proceeding to the south coast, are descendants of early streams which first determined the main direction of Wealden drainage. Rivers of this type, the direct consequence of land uplift, are called **consequent streams.**

As the work of these early streams progressed, the central portion of the chalk dome was slowly removed with the exposure

of the Greensand, Weald Clay, and Hastings Sandstone beneath, the last-named now forming the hilly central area of the Weald, while the clay forms the Vales of Kent and Sussex. The chalk has been left as an oval ring of hills around the area, but the process being gradual, the rivers have steadily cut gaps through the chalk. These gaps are used by the Southern Railway in linking London to important towns on the south coast. Near each gap an important town is situated by reason of the lines of communication, examples being Maidstone (15), Dorking (2), Guildford (1), Lewes (12), and Newhaven (13).

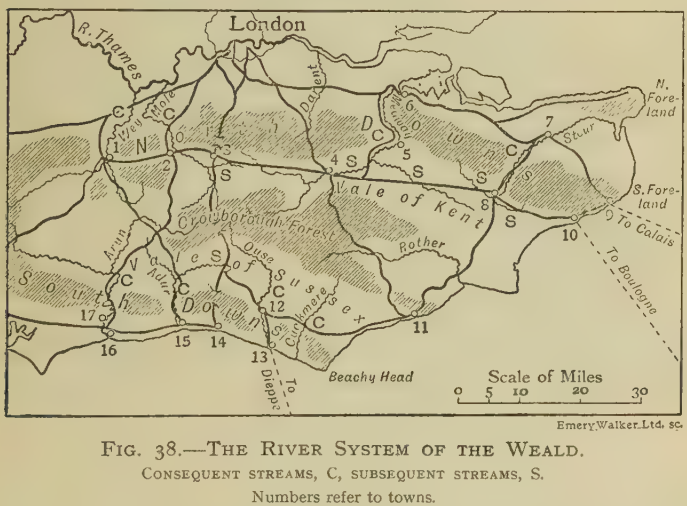


FIG. 38.—THE RIVER SYSTEM OF THE WEALD.
CONSEQUENT STREAMS, C, SUBSEQUENT STREAMS, S.
Numbers refer to towns.

As the process of Wealden denudation continued, later tributary streams flowing roughly east and west developed in the Weald Clay, and these are known as **subsequent streams.** Since these later rivers flow in valleys parallel with the chalk and greensand ridges, they are often described as **longitudinal,** in contradistinction to the earlier rivers which flow in **transverse** valleys more or less at right angles to the chief ranges of hills. In the process of denudation a river may be so modified that eventually part of it may be longitudinal, and other parts trans-

verse. This is the case of the Medway, which remains transverse where it flows through its gap in the chalk.

The relative values of both types of valley can be estimated by reference to the trans-Alpine railway routes (Fig. 39). The St. Gothard route which connects Lucerne with Bellinzona penetrates the centre of the Alps by means of two transverse valleys, that of the upper Reuss on the northern side and that of the Ticino on the southern side of the Alps. Similarly the Mount Cenis route connecting south-east France with north-west Italy,

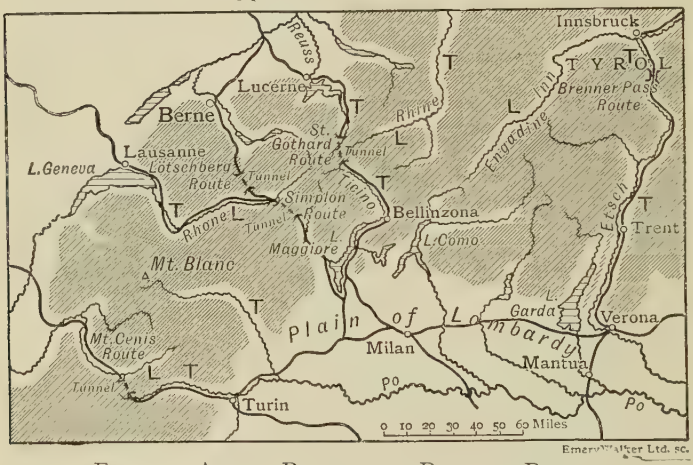


FIG. 39.—ALPINE RIVERS AND RAILWAY ROUTES.
LONGITUDINAL VALLEYS, L, TRANSVERSE VALLEYS, T.

and the Brenner Pass route linking the Tyrol with the Plain of Lombardy, make use of valleys mainly transverse in character. The Simplon route, however, uses the Rhone Valley, which is partly transverse though mainly longitudinal. Where mountain ranges have to be crossed, it is obvious that *the transverse valleys determine the main lines of communication.*

In time, even a high mountainous region like the Alps may be worn down by rivers so that a fairly level **peneplain** is produced. Should such a denuded country be uplifted by earth movement, the rivers gain a new lease of life and the system is said to be **rejuvenated.**

Frost, wind, and sunshine are important auxiliary factors operating in changing the landscape. Water in becoming ice expands and exerts considerable pressure on the sides of cracks and crevices in rocks, thus loosening fragments of various sizes. Wind transports loose fragments from one place to another, and this is particularly the case with the finer particles of sand, which are often carried from a shore line to a considerable distance inland unless impeded by vegetation. Heaps of sand, or **dunes,** often 60 feet high, are constantly being shifted by the wind, and in some cases ancient cities as those in the Desert of Gobi in Asia have been completely buried.

An interesting **aeolian** or wind-borne deposit, found chiefly in northern China though to a lesser extent in eastern Europe, is called **loess,** and is composed of fine particles of clay which have been blown into valleys forming deposits sometimes thousands of feet thick.

Sand and other fragments blown by the wind scratch and wear away other rocks in the course of time. The wind thus causes destruction as well as transport. The effect of the sun's heat is to provide material capable of being transported by wind. The sand of the desert is due to alternating expansion of rocks by heat during the day, and contraction on cooling at night. In some cases the surface layer of bare rock peels off under the influence of heat, a process known as **exfoliation.**

ICE AS AN AGENT IN MODIFYING SURFACE FEATURES

Where the temperature of the air is sufficiently low, snow falls instead of rain. Near the earth's poles snow and ice collect at sea level, but on the equator only the higher parts of mountains above 16,000 feet are capable of retaining snow all the year round. The **snow line,** or altitude at which snow remains throughout the year, varies with latitude, being above 8500 feet in the Alps, the latitude of which averages 46° N. No mountains in Great Britain are sufficiently high to reach the snow line, although the altitude of the snow line would be considerably lower than that in the Alps.

The lower portions of snow in a mountain snowfield are pressed into a compact mass of ice, portions of which slowly descend the valleys as **glaciers.** Pressure lowers the temperature at which ice melts, so that as the ice presses against the floor and sides of the valley it melts, turns a corner, and then re-freezes to a firm mass again. In this way a glacier adapts itself to the shape of its valley. But the valley does not have things all its

FIG. 40.—AN ALPINE GLACIER
WITH MORAINES, GROOVED ROCKS, AND ALPINE FLORA.
(By courtesy of the Swiss Federal Railways.)

own way. Lumps of rock of various sizes are torn from the floor, become embedded in the ice and act as erosive tools which scratch and grind the bed and sides of the valley. Scratches and striae and rounded rocks remain in a valley as evidences of former glaciation long after glaciers have disappeared, owing to a change in climate. These rocks are called **roches moutonnées** because, as explained by De Saussure, who first applied this term

to them, they "unite to produce the effect of a good thick fleece, or of those wigs that are also styled moutonne." Large numbers of fragments and boulders also fall from the valley sides on to the moving glacier and form heaps of rubbish called **moraines** which are carried by it down the valley to the place where the ice melts. Here all this moraine matter carried either on or in the ice is deposited in a heap forming a **terminal moraine.**

Old moraine material deposited by glaciers of a bygone age form extensive deposits called **boulder clays** which contain **erratics** or lumps of rock often carried long distances from their original sources. Thus, boulders of Norwegian rocks have been formerly carried across the site of the North Sea and deposited in the east of England. Sometimes large erratics are quietly dropped by melting ice upon some ledge or other peculiar position when they are known as **perched blocks.**

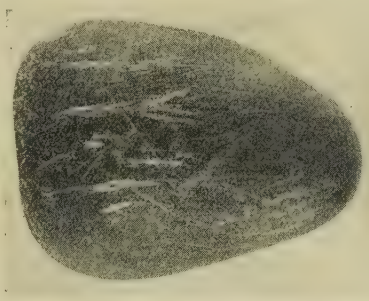


FIG. 41.—A BOULDER ROUNDED AND STRIATED BY GLACIAL ACTION.

(Photo. by G. S. Sweeting of specimen in the Geological Collection of the Imperial College of Science.)

There is no lack of evidence concerning the former glaciation of the British Isles and many other countries, including places now tropical like India and Australia. Boulder clays, erratics, etc., tell a true tale, and even the directions along which the ice moved can usually be deciphered by the study of striae, roches moutonnées, and erratics. Collected evidence shows that so far as Great Britain and northern Europe are concerned *there have been several ice ages with intervening warm periods.* When the ice mantle assumed its greatest proportions it did not quite reach the present position of the Thames. Southern England, then joined to the continent of Europe, was a land where primitive man pitted his wits against cave bears, hyenas, and the mammoth.

Deposits of boulder clay on the hill slopes of northern Britain have in many cases produced a better agricultural soil than

otherwise might have been the case, but the chief result of glaciation is the production of fine scenery, or at any rate, the improvement of mountain scenery which already exists. Deep U-shaped valleys have been carved by the downward erosion of great weights of ice, while high above the main valleys, water descends as falls from smaller ' hanging valleys ' due to little tributary glaciers that did not dig very deeply. The Staubbach near Lauterbrunnen in the Bernese Oberland is typical of such falls (Fig. 42).

The higher part of the Alpine region is the scene of the most flourishing ' tourist industry ' in the world. The dry powder-like snow annually draws thousands of visitors for winter sports while the beautiful lakes offer an equally attractive summer season. Formerly, the Alpine glaciers descended much lower in their valleys, and the scouring action of ice and stones carved long and deep hollows called **rock basins** which are now occupied by water. In the north-west of England smaller narrow lakes radiating from Scafell are due mainly to glaciation. In some cases a deposit of boulder clay across a valley has dammed a stream and thus produced a lake. Many of the Scottish lakes and the small mountain tarns of North Wales owe their existence to similar processes.

So far we have considered only glaciation of the **Alpine** type, but there is another kind known as the Greenland or **Polar ice cap** type. In this, a thick mantle of ice many thousands of feet thick covers enormous areas, and the border of this icy mantle forms high glistening cliffs. Boulders torn from the ground under the ice cap form a ground moraine which, owing to the irregular surface of the ground, may work upwards through the ice in places forming heaps called **nunataks.** Where the border of the frozen mantle reaches the sea, huge masses of ice break off and float away as **icebergs.** These drift to lower latitudes where they finally melt, and it is of great importance that shipping should, when possible, keep to the south of the limit of ice floating in the North Atlantic. Collision with an iceberg was responsible for the sinking of the *Titanic* in the summer of 1912, one of the greatest disasters that has ever happened at sea. An International Ice Observation and Ice Patrol in the North Atlantic is

FIG. 42. THE VALLEY OF LAUTERBRUNNEN, BERNESE OBERLAND.
A FINE EXAMPLE OF A DEEP U-SHAPED GLACIAL VALLEY. THE STAUBBACH WATERFALL IS SEEN ON THE RIGHT.
(By courtesy of the Swiss Federal Railways.)

now maintained which warns shipping of the positions of icebergs. The cooling of the air by bergs off Newfoundland causes extensive fogs, another source of danger to ships passing between Canada and Great Britain. The great Antarctic ice cap is even larger than that around the north pole though of a very similar type.

DESTRUCTIVE AND CONSTRUCTIVE WORK OF THE SEA

The action of the sea, though usually of a destructive character, is in some cases constructive. The large shingle deposit of Dungeness, and many square miles of new land near Rye in Sussex, formed since the Roman occupation, are examples of such constructive work. In many cases drifting sand and shingle is a nuisance, necessitating the construction of **groynes** which to some extent control the transport of pebbles by the sea. The larger features of coastlines : headlands, cliffs, level stretches of sand, estuaries and indentations of various shapes, etc., are determined by three main factors—*the destructive force of the sea*, *the kind of rocks*, *and the arrangement of these rocks*.

The destructive force of the sea depends partly upon tides and currents, though chiefly upon the pounding force of waves which use lumps of shingle as battering rams with which to make further inroads into the land. On the other hand, a foreshore of large blocks may sometimes afford a measure of protection to the land behind it. A fairly level strip of foreshore formed in this way is known as a **plain of marine erosion.** The kind of rock facing the sea is, perhaps, the main factor. In general, hard rocks such as granite, limestone, sandstone, and basalt will form cliffs presenting a fairly uniform front to the sea. The coast-line of North Devon between Minehead and Barnstaple, where hard old slates and grits extend along an almost unbroken front for 25 miles, is an excellent example of this. Soft rocks, like clay or shale, are worn away more quickly. If soft rocks extend over long distances and the destructive power of the sea is uniform, a fairly straight but low type of coast will result, but where soft rocks alternate with harder ones, an indented coast is

produced, the softer material being the bays, the harder rocks forming the headlands. Many parts of the coasts of Wales and of western England afford good examples of this differentiation. The part of Pembrokeshire near St. David's Head (Fig. 43)

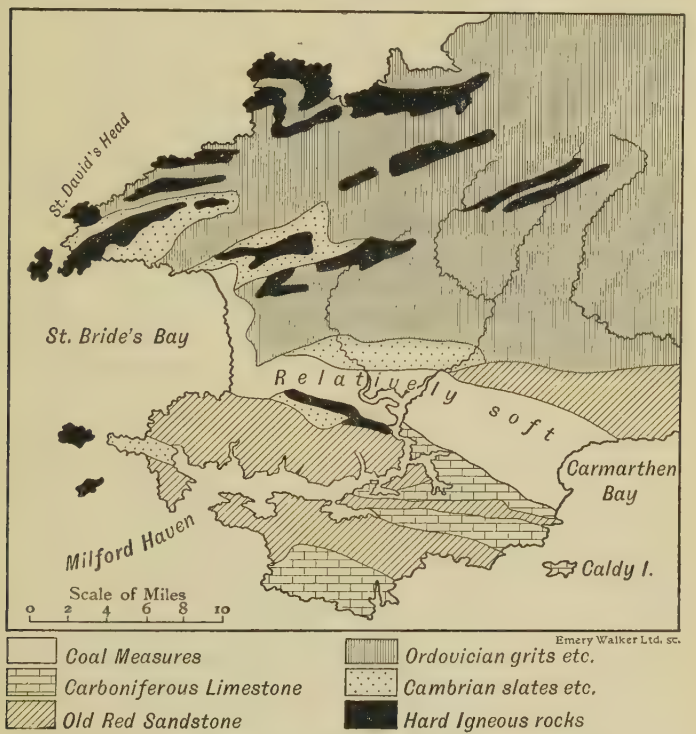


FIG. 43.—GEOLOGICAL MAP OF PEMBROKESHIRE.

shows promontories composed of hard igneous rocks alternating with sedimentary sandstones, etc., which, though hard, are soft in comparison with the igneous material.

The influence of rock arrangement is well illustrated by the south-west coast of Ireland, where the sea works against a series of anticlinal and synclinal folds, the result being several long narrow gulfs or creeks coinciding with the synclines. A fiord coast like that of western Scotland or of Norway is due to a

different cause. Here the great number of inlets or fiords are really old land valleys which have been drowned by the sea owing to the land having subsided. Of course, marine erosion still proceeds, but the main configuration of such coasts is due to slow sinking of the land in relation to sea level. The edges of continental masses slowly rise in some places and sink in others, as shown by old raised beaches on one hand, and submerged forests like that in Cheshire on the other. Many of the world's finest harbours and industrial waterways are formed by this slow secular subsidence, the Firth of Clyde being a famous example. Parts of the ocean floor also rise or sink slowly as shown by the great naturalist Charles Darwin, who inferred from the great depth of coral structures in coral islands, that the lower parts of such islands must once have been nearer the ocean surface, since the reef-building coral animals can live only in shallow water.

CHAPTER V

PLANT LIFE AND PRODUCTS

No man can say exactly what life is, or how and when it originated. Living creatures—both plants and animals—differ from non-living or inorganic matter in being able to assimilate foodstuffs and so build up and repair their tissues, in their power of secreting or excreting substances, in being able to reproduce their kind, and in their ability to adapt themselves more or less to their environment or surroundings. But we are still unable to define Life.

There is, however, a fundamental jelly-like substance called **protoplasm** containing the elements carbon, oxygen, hydrogen, nitrogen, and sulphur, and all living things are composed of this substance which Huxley described as 'the Physical basis of Life.' The chemical elements composing protoplasm occur in many forms of non-living matter, and it may be that living organisms of an extremely simple kind developed from inorganic substances under unknown conditions which existed on the earth many hundreds of millions of years ago.

The geological record is silent concerning the first creatures which must have inhabited the earth, the chief reason for this silence being the fact that the simplest types of organisms, then as now, were probably without hard parts capable of being fossilised. In the far north-west of Scotland occur ancient sediments, the so-called 'Fucoid beds,' containing markings closely resembling the form of seaweeds, though these may be only of mineral origin. The earliest fossilised animal remains consist of sponge spicules, impressions of jelly fish, early types of shells, and others which must have had a long line of simpler ancestors preceding them, but the remains of these have not

been found. In view of the extremely simple structure of the lowliest organisms living to-day, this unfortunate gap in the geological record is exactly what we should expect to find. But after this gap, the record of the rocks more than makes amends by the enormous amount of evidence it supplies in support of the theory that the various species or kinds of living things have slowly evolved from earlier and simpler ancestors.

The facts of evolution were first investigated adequately by the great naturalists **Charles Darwin** and **Russell Wallace.** Darwin's book *The Origin of Species*, published in 1859, after more than twenty years of careful observation and experiment, produced as great a revolution in scientific thought as did Newton's work on gravitation. Stated very briefly, the theory of evolution explains the different species of animals and plants as being due to variations in all living creatures of any particular group, and the struggle for existence by which some creatures adapt themselves to their surroundings better than others have done. Those which alter in such ways as to fit them better for the struggle for life survive, whereas those groups which do not adapt themselves adequately, eventually die out or become extinct. Constant adaptation and improvement in both the plant and animal worlds have led to the formation of innumerable **species**, and ' the survival of the fittest.'

Though environment, or an organism's surroundings, is an important factor in its development, there is another equally important factor known as **heredity,** in virtue of which certain characteristics and tendencies are passed on from one generation to the next. The extent to which heredity may influence later generations has been investigated by many different naturalists, but particularly by **Mendel,** a former Abbot of Brünn, in Austria, whose discovery of certain principles of inheritance is of deep significance in the study of biology. An adequate discussion of both ' Darwinism ' and ' Mendelism ' is, of course, beyond the scope of this book, and we must now pass to a general consideration of plant life.

SIMPLE PLANT AND ANIMAL FORMS

Living at the present time are an enormous number of very simple minute organisms, both plants and animals, and others which resemble plants in certain ways and animals in other ways. At the bottom of the scale of living creatures the vegetable and animal worlds overlap, and it is reasonable to suppose that both kinds of the creatures which form two such well-defined groups to-day, originated from simple common organisms, though they soon diverged along two widely different lines. If we consider one of the simplest of minute plants and compare it with one of

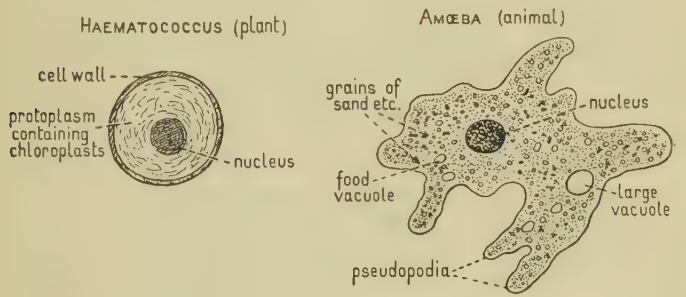


Fig. 44.—Unicellular Organisms.

the simplest of animals, we shall be able to obtain some ideas concerning the similarities and differences of the two classes of organisms.

The green slimy substance which collects in water butts consists of great numbers of microscopic spherical plants called *Haematococcus pluvialis* (Fig. 44). Each unit or cell is a complete plant in itself, and is composed of protoplasm, though different structures are seen at different parts of this protoplasmic substance. On the outside is a containing wall consisting of material called **cellulose** * derived from the protoplasm, and it is this cellulose that builds a more or less firm casing which pre-

* Cellulose of older woody plants becomes impregnated with a substance called lignin, so that the physical properties are not quite the same as those of young cellulose.

serves the shape of plants whether they are microscopic and *unicellular* (*i.e.* one cell only), as Haematococcus, or large, and composed of millions of cells as an oak tree. Near the centre is a darker portion of protoplasm called the **nucleus** which controls the life and reproduction of the plant. Between the nucleus and the containing wall is a mass of protoplasm, containing granules or **chloroplasts,** coloured green by a substance termed **chlorophyll,** probably the most wonderful substance in the world. *Chlorophyll enables plants to obtain energy or power from sunlight for the construction of organic foodstuffs and hence to build up fresh protoplasm from non-living inorganic substances got from the air and from the soil.* The great majority of animals have no chlorophyll and therefore cannot live on inorganic substances; they must obtain their supplies of protoplasm from other animals or from plants. Without plants, animal life would be impossible, hence *the main use of vegetation is the production of food for animals.*

In plant cells generally, there are usually some apparently empty spaces termed **vacuoles** and these contain a watery fluid commonly known as **cell sap.** Simple unicellular plants like Haematococcus and Bacteria multiply or reproduce by a process of division. In Haematococcus the nucleus divides into two, four, or more parts, each part taking so much protoplasm, and becoming a separate organism liberated by the breaking down of the old cell wall. The new individuals composed of naked protoplasm are in this particular species pear-shaped and provided with two thread-like **cilia,** the motion of which causes the little creatures (in this form called **zoospores**) to swim about, but after a short time they build new cell walls, withdraw the cilia, and become ordinary staid Haematococcii similar to the parent organism. Reproduction by this means of division is said to be **asexual** since there are not two different sexes concerned with the process as there are in the higher plants and animals.

Now consider one of the simplest of animals, a microscopic creature, called **Amoeba,** found in the soil and in ponds (Fig. 44). Like the Haematococcus this organism is composed of one cell possessing a nucleus, the division of which leads to reproduction. Cavities or vacuoles are present, one large vacuole being con-

nected with the control of water in the organism, the others usually being spaces formed during the process of food capture. This creature differs from the simple plant in several ways. There is no definite cell wall composed of cellulose and there is no chlorophyll, hence its food must consist of *protoplasm* obtained from other organisms. These other organisms must be caught, and in order to do this the Amoeba, having no rigid wall, constantly changes its shape, sending out **pseudopodia** or projections of protoplasm which wrap around the food, and the whole organism 'flows' along. Such food as is not absorbed is excreted or thrown out of the cell; it *reaches* the surface of the organism and is left behind as the organism moves about. The organism is capable of considerable movement and is said to be *motile*, whereas in a plant the protoplasm moves within the cell but the cell as a whole is usually *non-motile*. These facts are equally true for large plants and animals. A plant is rooted to one place and has its food brought to it by water and air, while nearly all animals move about in search of food and consequently live a very active life in most cases.

Some of the friends, and unfortunately many of the greatest enemies, of mankind are microscopic unicellular plants called **Bacteria,** which multiply at an enormous rate, many millions being produced from a single organism in a few hours. Friendly or useful bacteria are made use of in the manufacture of vinegar, in preparing for use the fibres of flax, hemp and jute, in causing cheese to mature, while others in the soil assist in the preparation of nitrogenous compounds for plant food; the hostile varieties include the 'germs' which produce deadly diseases such as consumption, cholera, diphtheria, typhoid, and many others with which man is always at war, as well as bacteria producing undesirable fermentation in foodstuffs such as that which causes milk to become sour.

FUNGI AND THALLOPHYTA

Another useful unicellular plant of considerable interest is **yeast,** employed in baking and brewing. A yeast cell is rounded, has a definite cellulose wall, and usually several vacuoles are

present. But it differs from the plants we have considered in having nuclear matter though no proper nucleus, and in the absence of chlorophyll. This means, of course, that there is no green colouring matter, and as the organism is thus incapable of building up protoplasm from inorganic matter, it must live on already prepared foodstuffs, such as sugary liquids. It multiplies by giving off little bud-like growths, which break away from the parent organism and become complete yeast cells. Such a mode of reproduction is called **budding.** But when yeast is kept warm (87° F.), the cells multiply in a different manner. In these circumstances each cell divides into four equal parts, each part building a cellulose wall and containing a share of the protoplasm, forming bodies called **spores,** which retain their vitality for a long time, and may be caused to develop or ' germinate ' later on. The ability of yeast to produce **fermentation,** a process in which sugar is converted to alcohol, is the reason for its use in the manufacture of beer. Beer is an artificial product, and the yeast used for it is cultivated, but in vineyards, yeast cells exist naturally in the soil. Substances like that in yeast which produce fermentation are called **enzymes.**

In the multicellular plants, either simple or more advanced types, great numbers of cells combine to form structures called **tissues,** and these tissues also combine to construct **organs** such as roots, leaves, and flowers. There is an exceedingly great variety of multicellular plants, some much more advanced in structure and function than others. Among the lower types of such plants are the **Fungi,** which include edible mushrooms (Fig. 45), and poisonous toadstools. These resemble yeast (a unicellular fungus) in having no chlorophyll, hence they are not green, and either live as *parasites* on other plants, obtaining the foodstuffs which these other plants manufacture for themselves, or subsist upon dead organic matter (*saprophytes*). Thus, the common mushroom grows upon decaying vegetable matter in open fields, and is cultivated on prepared ' beds ' in cellars.

These plants multiply by means of minute dust-like spores obtained from the mature blackened **gills** on the underside of the **pileus** or upper umbrella-like part of the mushroom. In fact, the so-called mushroom is simply a spore-producing

structure, the main portion of the plant consisting of a mass of whitish threads extending through the underlying soil. Mushrooms are cultivated from **spawn** which is composed of these whitish threads made into a compact mass with manure. When parts of a plant, such as these threads, develop into a complete plant, the process is known as **vegetative reproduction,** a process often artificially employed in gardening when cuttings are taken and planted in the soil, or when buds are grafted on to a well-established plant. Another interesting case is afforded by the

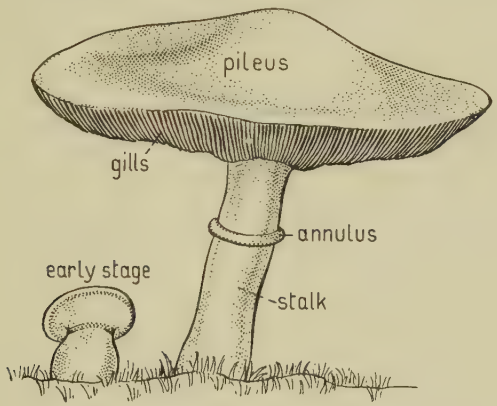


Fig. 45.—The Common Mushroom.

strawberry, which sends out horizontal runners or shoots along the ground, the new plants developing from the nodes or outgrowths on the runner while the rest of it decays. Most of the plants which arise from bulbs are other examples.

Since fungi contain no chlorophyll and therefore sunlight plays no part in their existence, they can grow well in the dark, and some of the moulds and mildews which collect on food, leather, and other objects in damp places belong to this group of plants. A very interesting case which may be regarded as a partnership between a green organism manufacturing food and a spore-producing fungus is afforded by the various lowly plants termed **Lichens.** These are found as greyish incrustations on stones and other objects. The fungus part of the arrangement is

recognised by the brownish flat or cup-like spore-producing structures.

Among other primitive plants are the seaweeds belonging to the group called **Algae,** one of the best known being *Ulva*, the weed growing on piers and breakwaters. In this, the plant body is ribbon-like, though there is no differentiation into plant parts or organs as found in the higher divisions. Such a plant body, merely a flat expansion, is called a **thallus.** Seaweeds contain chlorophyll, though sometimes the green colour is more or less masked by brown colouring material as in *Fucus*, the common branched weed of the seashore. The ash of burnt seaweed, called **kelp,** is a valuable source of iodine. Other Thallophyta include mosses and liverworts, which are pronounced moisture-loving plants, found on damp earth in early spring, in corners near brooks or in crannies of wet hedge banks.

Of the flowerless plants or **Cryptogams** the more advanced in structure and function are the ferns which, to some extent, resemble the flowering plants in possessing definite roots, stems, and leaves. The club-mosses of moorland, the horsetails of swampy places, and certain other plants are related organisms. The structures exhibited by ferns and the life-history of their spores are very complicated and a description is not possible here. Enormous strides in development separate the simple Thallophyta from the ferns, and it is interesting to note that the great Carboniferous forests of long ago which have left us such a rich legacy of coal were composed mainly of gigantic ferns and huge members of the horsetail family.

FLOWERING PLANTS

In most of the vegetable types we have considered, reproduction usually takes place by means of spores—unicellular bodies which become detached from the parent and then develop as separate plants. In the higher plants which we are about to consider, the **Phanerogams,** reproduction takes place by means of **seeds,** which are multicellular and complex bodies in which a young plant or embryo must be formed before the seed is set free from the parent. In most flowers there are male organs of

reproduction and female organs, and since a female cell or **ovum** is fertilised by union with a male cell or **pollen** grain, this mode of reproduction is described as **sexual reproduction.** Usually, both the male and female organs are present in the same flower, when it is described as **hermaphrodite,** examples being most of the familiar flowers seen in the herbaceous borders in our gardens. In some plants, as in the vegetable marrow and the hazel-nut

FIG. 46.—REMOVING COCOA BEANS FROM THE PODS.
(By courtesy of Messrs. Cadbury Bros. Ltd.)

and oak trees, there are two distinct flowers on the same plant, but in relatively few other cases there is a definite male plant and a separate female plant as in willow, and poplars. Yet another type of reproduction is exhibited by many flowering plants: roses, daisies, and others which can develop from true ova without fertilisation by a male cell. Such a process is termed **parthenogenesis.** But in all cases, no matter which mode of reproduction is employed, every living thing originally comes from a primitive simple cell.

THE ORGANS OF A PLANT AND THEIR FUNCTIONS

Although the number of different flowering plants is exceedingly great, typical examples are all built more or less according to a general plan, each consisting of four parts or organs—root, stem, leaves, and flower. Each of these parts performs definite functions contributing to the general life of the plant, which may be illustrated best by reference to one well-known example, say the Wallflower. If possible, obtain one of these, wash the soil from its roots, and examine the plant carefully.

The **root** consists of numerous yellow or pale brown branching structures which taper to pointed extremities. This branching and twisted arrangement enables this part of the plant to come into contact with as much soil as possible, so that a good supply of material for food manufacture in the higher part of the plant may be obtained. The root itself has no chlorophyll. Attached to the roots, particularly the more slender parts, are many fine thread-like **root-hairs** through the cellulose walls of which soil water passes to the inside of the plant by a process called **osmosis** in which liquids pass through a separating membrane, in this case the cellulose wall. The weak solutions which pass into the root-hairs have to be forced upwards through the stem into the leaves of the plant. Several factors contribute to this forcing process. The water of the soil continues to pass into the roots and hence produces what is termed **osmotic pressure,** and the root itself exerts a **root pressure,** while **capillarity** or the ability of very narrow tubes to suck up liquids also assists in causing water to pass right through the plant. Finally, water not utilised by the plant is discharged as water vapour into the atmosphere by way of the leaves. This passage of water through the plant is called **transpiration,** and all of the means by which it is accomplished are not yet fully understood. Roots also serve as a means of anchorage for the plant.

The **stem,** which in this case is branched, consists of numerous more or less upright rod-like structures which are angular in cross section. Each portion of the stem contains numerous slight outgrowths called **nodes,** which are the positions at which leaves and branches arise from buds, the comparatively smooth

parts between the nodes being known as **internodes.** The stems are green, particularly when young, and contain chlorophyll, so that a certain amount of food formation occurs, and this is assisted by numerous pores or **stomata** which permit the gases of the atmosphere to enter. But the chief functions of stems are the construction of a suitable scaffolding upon which the leaves may be extended to meet the sunlight and air, and the conveyance of the plant fluid or sap to the leaves.

The **leaves** of a plant constitute the chief food factory of the organism. Generally the more leaves there are the better, and the wallflower is no exception to this, there being dozens of leaves on a single plant. Each leaf is flattened, elongated, rather narrow, and has a gently curved non-indented outline (compare the indented leaf of a buttercup). The flattened part, called the blade, is attached by a little stem or **petiole** to the main stem. Extending down the middle of the leaf is a primary **vein** from which other veins extend on each side, and these secondary veins bear still smaller ones. This system of veins is connected with the water supply which passes upwards from the stem and roots, so that the water and dissolved salts from the soil which it contains are brought to the food-producing factories.

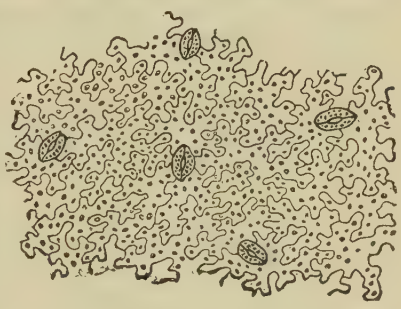


FIG. 47.—PART OF A LEAF SHOWING STOMATA HIGHLY MAGNIFIED.

How is this food manufactured by leaves? Though a leaf is covered by a thin membrane or cuticle, this is pierced by numerous oval openings or stomata which admit carbon dioxide from the air (Fig. 47). Under the influence of sunlight the chlorophyll causes the carbon of this gas to combine with water to form sugar and starch, which are known as **carbohydrates.** Unused oxygen is returned to the air, so that during the daytime green plants are improving the condition of the air for animals which require oxygen but not carbon dioxide. It must not be

imagined, however, that plants do not require oxygen. They breathe or respire air for the sake of oxygen as animals do, though no special organ is set aside for this purpose. It may be said that respiration takes place all over the plant's body.

The formation of sugar and starch by the influence of sunlight is called **photo-synthesis,** and it is this process that makes life, as we know it, possible. These carbohydrates contain carbon and water, while the solution passed up from the soil supplies not only water but also nitrogenous matter, so that by further synthesis, or ' building up,' new protoplasm is obtained, and the plant grows. Leaves, so vital to the living plant, are also valuable economic products for man ; for example, cabbage and related vegetables are chiefly leaves, while tea and tobacco are also leaf products.

Water is required as a food and as a carrier of other foods in the process called transpiration. Since water passes out as vapour through the stomata of leaves, many plants run the risk of losing too much water, hence some means of checking this loss must be employed. The stomata themselves are of adjustable size, being regulated by two surrounding **guard cells,** but this is in many cases insufficient. In cold weather of the winter months, transpiration is checked by the shedding of leaves in the case of **deciduous** trees, while in those **evergreens** which inhabit cold countries various adaptations of the leaves themselves produce the required result. Pines and firs have tough needle-like leaves with their stomata sunk in depressions, so that they are not too exposed to the air. In desert plants, moisture must be carefully conserved and this is accomplished by spiny and hairy leaves on a fleshy stem having a waxy surface, as in Cacti, and sometimes water is stored in these stems. A few plants may get too much water and in such cases broad surfaces lead to much evaporation, or water may drip from points.

THE FLOWER

The large number of little flowers together form what is termed an **inflorescence.** Examine one of the florets (Fig. 48) of the wallflower and it will be observed that the lower part of it, where

it joins the **pedicel,** or last part of the stem, is composed of four little curved blade-like structures or **sepals** which together form a cup, the **calyx,** in which the other parts of the flower rest. The largest part of the flower, the coloured **corolla,** comes next, and this is composed of four petals surrounding a hollow which contains the organs of reproduction. Both male and female organs are present, so that the plant is hermaphrodite. The male organ or **androecium** is composed of six pillar-like structures called **stamens**—two shorter ones towards the sides and four taller ones nearer the middle. Each stamen consists of a filament supporting a sack-like body, or **anther,** containing the male cells or pollen grains. The female organ or **gynoecium** placed in the centre is an elongated vessel, the **ovary,** containing numerous **ovules.** There are two sides or **carpels** which unite to form this vessel and at its summit are two pointed structures, each of which is called a **stigma.** The ordinary domestic pea-pod is a larger but similar vessel containing ovules (peas), the two sides of the pod which later separate being the carpels.

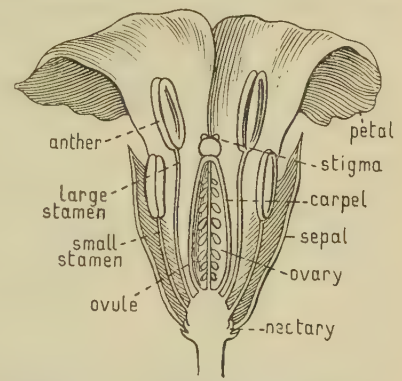


FIG. 48.—LONGITUDINAL SECTION SHOWING STRUCTURES OF A FLORET OF THE WALL FLOWER.

In the process of fertilisation the anthers burst or **dehisce,** causing the yellow dust-like pollen to fall upon the stigma of the female organ, whereupon the pollen grains may germinate. A slender pollen tube grows out from a pollen grain, pierces the tissues of the female organ and grows right down to the ovules within the ovary. But the flower does not rely altogether upon the pollen *falling* upon the stigma. At the base of each of the two lateral stamens is a kind of gland or **nectary** which secretes a sweet honey-like substance for the purpose of attracting insects, which incidentally pick up some of the pollen grains and transfer

them to the stigma. The beautiful colours of flowers also assist in the attraction of insects. Cases in which pollen is carried from one flower to another by insects or by the wind are examples of **cross pollination,** which is, of course, essential for the fertilisation of flowers that are not hermaphrodite. Generally, the pollen will fertilise only another flower of the same kind, but occasionally a member of a different family may be fertilised, the resulting plant being known as a **hybrid.**

The various parts of the wallflower should be compared with those of other flowering plants in order that variations in the shape of the leaves, in the number of sepals, petals, and other features may be noted. Simple plants such as the dandelion, buttercup, primrose, etc., make good material.

THE DISPERSAL OF SEEDS AND FRUITS

The ova being fertilised, the carpels and their contents constitute the **fruit**—the part of the flower that remains after the sepals and petals have dropped. Usually the ova are surrounded by matter, the **endosperm,** which later will act as a supply of food for the young embryo during the early stages of its development before it has roots and leaves available for the production of its own foodstuffs. The fertilised ovum with its surrounding food supply is known as a **seed** (in a fruit there is usually a large number of seeds) and this little body remains dormant or inactive during the winter months. When spring comes the seed awakes, water enters through a minute aperture, the **micropyle,** the covering swells, a tiny root or **radicle** appears, then the

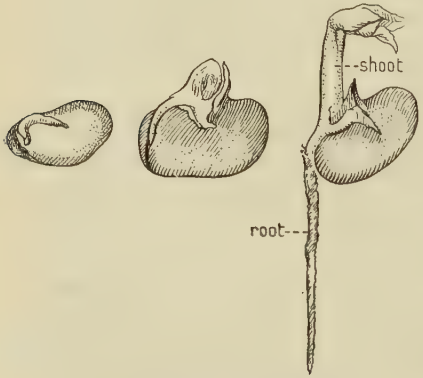


Fig. 49.—Three Stages in the Germination of a Bean.

plumule or first stem emerges and grows upwards (Fig. 49). This early process of development is called **germination,** and for seeds to germinate successfully sufficient oxygen for respiration must be available, while there must also be moisture, and the temperature must generally be considerably above freezing point.

In order that the young plants may develop freely, the seeds must be taken from the parent plant and placed in soil preferably elsewhere to avoid overcrowding, *i.e.* they must be dispersed. Many seeds, such as those of the dandelion, develop hairy fibres, so that they may be carried by the wind. This device for **wind dispersal** has supplied us with a most valuable material in the dirty white fibres around the seeds of the cotton plant (*Gossypium*), which is related to the Golden Hollyhock and wild Mallow. These fibres vary in length from $\frac{1}{2}$ in. to $2\frac{1}{2}$ in., while the seeds are about the size of small peas and contained in pods or **bolls,** about 75 of which yield a pound of raw cotton. After the fibres have been removed by a suction process, the seeds are crushed for the extraction of oil, and the residual pulp, which still contains some oil, is then pressed and made into oil-cake, a valuable cattle food. Though originally a perennial, the plant is now cultivated as an annual in warm countries, chiefly the United States, Egypt, and India. In some other plants, burdock for example, structures like hooks cause the fruit to adhere to a passing animal, while the water lily has light and buoyant seeds which float away from the parent plant. But most plants disperse their seeds themselves by some method in which they are discharged from the carpels when the latter burst or dehisce, sometimes, as in the sweet pea, curling or twisting of the carpels causing the seeds to be thrown in all directions.

PURPOSES AND USES OF FOOD STORAGE IN PLANTS

The process of food storage in the seeds or other parts of plants is of great importance in connection with our own diet, since man often steps in and appropriates the food which is meant for the young embryonic plants. Cereals, such as *wheat*, from which we obtain **flour** for our daily bread, consist of fruits surrounded by food consisting of a mealy substance, largely starch (Fig. 50).

The grasses which feed our sheep and cattle are related plants, which are often consumed before they can mature. Many seeds store **fats** or **oils**, such as those found in olives, brazil nuts, flax (linseed), coconut, and the castor-oil plant, and often valuable nitrogenous foodstuffs called **proteins** are stored, particularly in *peas* and *beans*.

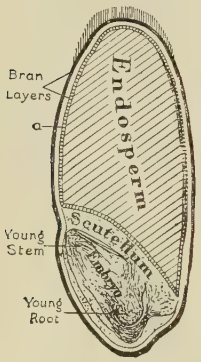


FIG. 50. — LONGITUDINAL SECTION THROUGH A GRAIN OF WHEAT.

The number of vegetable foods which man and his domesticated animals obtain from various fruits, leaves, and roots is too great to be discussed adequately here, but one or two others which constitute the basis of great industries must be mentioned briefly. In the **cocoa** and **chocolate** industries the natural product is the fruit of a tropical tree, the correct name of which is *cacao*. The tree is often 20 feet in height and the fruits consist of brightly coloured lemon-shaped pods often as much as ten inches in length, too large to be borne by slender stems, hence the flowers grow directly upon the trunk and thicker branches (Fig. 51).

Coffee is obtained from the seeds of the sub-tropical plant *Coffea arabica* and other related shrubs, which require a warm and moist climate but not so much heat as the cacao plant. Tea is made from the leaves of hardy shrubs related to *Camellia*, and, like coffee, must be regarded as a stimulant rather than a food.

Food storage is effected not only by seeds but also by other parts of plants, for example, by certain leaves as in an **onion**, which consists of a short stem having little adventitious roots below and two sorts of leaves above (Fig. 52). The outer white scale leaves are stored with food and surround the inner foliage leaves, which become green as they reach the light. An onion is a typical bulb and should be compared with others such as those of the tulip, hyacinth, and daffodil. A **potato** is a swollen underground stem or **tuber** rich in starch, and grown from older ' seed ' potatoes having ' eyes ' or buds which develop into new plants. Sometimes it is the root which becomes distended with

food, as in carrots, turnips, parsnips, and beetroots, the last named being extensively cultivated in temperate countries for the sake of the stored **sugar**, which is extracted by slicing the root and then immersing it in hot water. The remains of the beet after the extraction of the sugar is useful as a food for cattle.

Plants such as the beet are termed **biennials**, since their normal course of life extends over two years. During the first year they develop a great number of leaves which manufacture large

FIG. 51.—FLOWERS AND SEED PODS ON THE CACAO TREE.
(By courtesy of Messrs. Cadbury Bros. Ltd.)

quantities of food for storage, and if left undisturbed they flower and produce seeds in the second year.

The life cycles of plants vary considerably, and there are many which grow from seeds, become mature, and flower all in the same year and are therefore called **annuals**; others which keep growing and live for several years are **perennials**. The best known and most useful examples of the perennials are trees. In these, the valuable portion is frequently the trunk or stem, because woody cellulose is accumulated there which forms timber for building, etc. A section through a large tree trunk

(Fig. 53) shows several structures, chiefly the inner hard wood or **xylem**, next the softer sap wood, and on the outside the bark. The xylem of a great number of trees is known as **timber** or wood, and from wood pulp we obtain paper and other cellulose products, such as artificial silk. The barks of various trees yield cork, vegetable dyes, and certain drugs, such as quinine and cocaine.

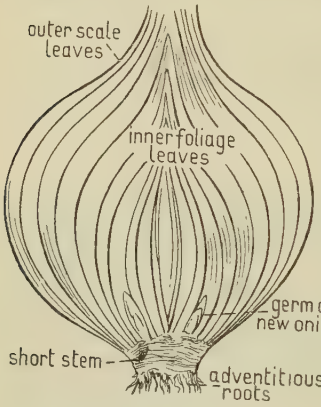


FIG. 52.—VERTICAL SECTION THROUGH AN ONION.

Certain trees when 'tapped' by incisions reaching just beyond the bark yield valuable fluids from which important products are obtained, such as rubber. Many species of tree, particularly that called *Hevea*, supply this commodity, and they may exist mainly in the wild state, as in Brazil, or in cultivated plantations, the latter being particularly the case in the Malay States, Ceylon, etc. The milk-like fluid or **latex** contains about 30 per cent. of rubber, which is obtained by causing the latex to coagulate by a smoke-curing process, the coagulating rubber being wound upon a stick, or by a process of electrolysis. Other products obtained by tapping various trees are gums, resins, and various 'essential oils' such as turpentine, eucalyptus oil, etc. Chaulmoogra oil, obtained from the seeds of Hydnocarpus trees which grow in southern India, Siam and China, is used in the treatment of leprosy.

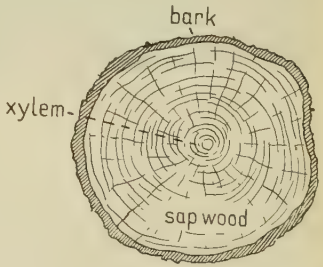


FIG. 53.—HORIZONTAL SECTION THROUGH THE TRUNK OF A TREE.

Besides the trunks of larger trees, the stalks of smaller plants are of considerable importance, particularly those of flax, the

longer fibres of which are made into **linen**, a material of great antiquity and used long before the introduction of the cheaper material cotton, the shorter fibres being made into string and cord. Flax is cultivated either for the seed or for the fibre, the plant being pulled up and not allowed to mature in the latter case. Jute and hemp are other fibres used respectively for sacking and rope.

CHAPTER VI

SOILS AND THEIR RELATION TO PLANT LIFE

THE common **soil** or earth in which plants grow is a rather complex substance though it is primarily produced by the gradual wear and tear of the rocks below. Rain, wind, sunshine, and frost all help in breaking up the firm rocks into small pieces, and in this work of soil making, plants themselves assist in no small measure, since their roots penetrate small cracks and spaces and organic acids produced by them react chemically with some classes of rock material. A natural section seen in a quarry (Fig. 54) often shows the transition of fine surface soil to lower coarser soil, then larger lumps forming the **sub-soil,** and finally the massive, unbroken rock beneath.

The dark colour of most soils, and many of the valuable constituents of it, are due to decaying, or already decomposed, plant material. Whether this organic residue is derived from earlier generations of grasses or from any other smaller or larger kinds of vegetation, it is known by the general name **humus,** and it is this material which supplies most of the nitrogenous matter required as food by living plants. The nitrogen in humus is not, however, in the form suitable for assimilation straight away, and later we shall note the means by which it is made suitable for plant food.

Most rocks of the world are of the sedimentary kind, and of these by far the largest number are sandstones, clays and limestones. Sandstones generally contain some limestone particles, or as it is generally termed, **calcareous matter,** also some particles of clay. Similarly most limestones contain a little sand and **clay,** while clays may be calcareous or sandy. From this, it follows that a soil is usually a mixture of all three, but with varying

proportion of each depending upon the nature of the rock below. In limestone areas, rain water containing carbon dioxide reacts chemically with limestone, removing some of it by solution, so that the resulting soil contains a higher proportion of sand and clay than it would do otherwise.

Each of these substances has its own work to do. Sand grains help to keep sufficient spaces for water and air between

FIG. 54.—A QUARRY
SHOWING TRANSITION FROM COMPACT ROCK TO SOIL.
(By courtesy of the Director, Geological Survey.)

the particles of soil, but if there is too much sand, as in a desert, the soil is far too porous and retention of water is inadequate. Clay particles exert a moderating influence in this respect, but if this substance forms too great a proportion the soil is heavy, cold, badly drained, and not sufficiently aerated. Another useful property of clay is its absorption and retention of substances formed when manures, potash, and lime are added to improve the soil. Calcareous matter serves as a means of neutralising the organic acids produced by the decay of vegetable matter or humus, and assists in the formation of **nitrates.**

A good soil for general purposes, usually known as **loam,** has roughly these constituents in the following proportions : sand about 60 per cent., clay about 25 per cent., calcareous matter and humus each about $7\frac{1}{2}$ per cent. The terms sand and clay are here used with their correct geological meaning, but they are often used to mean large and small particles of soil respectively, and this roughly agrees with the mineralogical significance, since the larger particles are normally composed of sand or silica and silicates, while the smaller particles are mostly of actual clay or hydrated silicate of aluminium. Another term often used in the description of soils is **marl,** which is given to a clay soil containing much calcareous matter.

Soils exhibit every gradation from light sands to heavy clays. The final product resulting from the breaking up of igneous rocks like granite and basalt is very similar to the soils obtained from the sedimentary rocks, since decay of felspar in igneous rocks produces clays, and the other constituents form ' sand.' The dark lavas are usually very rich in iron oxides. In addition to the sand, clays, and calcareous matter in soils, there are usually small proportions of many other substances containing iron, phosphorus, potash, sulphur, magnesium, and of course, there is always humus, and water.

RELATION OF SOIL BACTERIA TO THE PLANT'S SUPPLIES OF NITROGEN

With the exception of **carbon,** from carbon dioxide, and **oxygen,** both obtained from air, a plant receives its foods from the soil, and of these **water** is the most important, as it is not only a food itself but carries others in solution ; it also distends the plant cells and tissues so that they are *turgid*, and thus keep the leaves etc., in extended positions. The leaves of a plant receiving insufficient water soon wilt or droop. Water and air occupy the interspaces between the grains of soil, usually as much as one-third or more of the whole soil, depending on the kind of soil, consisting of these interspaces. By means of these spaces the surface soil sucks up water from the lower layers of earth. Of the other foods which are carried in solution in the water, the most important is **nitrogen** (necessary for the formation of

proteins), which exists in the atmosphere and in humus, but in neither case is it in a soluble form. How is its solution accomplished? Certain compounds of nitrogen termed **nitrates** are very soluble, and the nitrogen in humus must be converted to a nitrate before it can pass into solution.

The nitrogenous compounds in humus are of a complex character and are broken down into simpler compounds by certain kinds of bacteria which are present in soils in great numbers, many millions to every ounce of soil. As we have seen,

FIG. 55.—BACTERIA (*Bacillus radicicola*) FOUND IN THE NODULES OF LEGUMINOUS PLANTS. (*Photomicrograph Rothamsted Experimental Station.*)

bacteria are simple, very minute plants which multiply by division. There are several of these useful organisms, and they work in different ways. Now certain bacteria cause decaying organic matter or humus to liberate ammonia, which is composed of nitrogen and hydrogen, and another particularly useful bacterium called *Nitrosomonas* converts ammonia into an acid containing nitrogen, hydrogen, and oxygen which is known as nitrous acid. This reacts chemically with substances such as potash or lime in the soil, thus producing compounds called **nitrites.** Another bacterium, *Nitrobacter*, then changes nitrites

into nitrates which pass into solution and can enter the root hairs of a plant.

Other bacteria are capable of ' fixing ' ordinary atmospheric nitrogen ; that is, they can make it combine directly with other elements to form nitrogenous compounds. An important case of direct nitrification by the bacterium *Pseudomonas* is found in connection with plants of the pea and bean order, the *Leguminosae*. These bacteria enter the root hairs, multiply in large numbers, and so produce little nodular swellings on the roots.

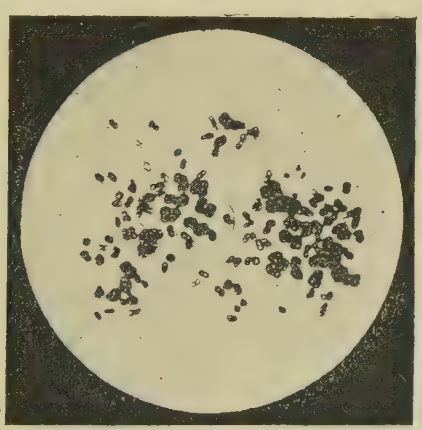


FIG. 56.—BACTERIA (*Azotobacter*)
FOUND IN ALL FERTILE SOILS.
(*Photomicrograph Rothamsted Experimental Station.*)

While they are there they ' fix ' nitrogen, but presently the plant absorbs them with the nitrogenous material they have formed.

Though these useful bacteria multiply at a great rate, they have their difficulties and their enemies. The acids which some of them produce are harmful to themselves ; hence the addition of powdered chalk or of lime, which neutralises acids, is beneficial. Then there are other bacteria, the *denitrifying* kinds, which take nitrogen away from compounds, thereby setting it free, and undoing the work of the others. This sort of thing occurs in soils which are badly drained and not supplied with sufficient air.

A constant warfare is being waged between the bacteria and

Protozoa, like *Amoeba*, which devour the minute vegetable organisms. The soil teems with life, not only microscopic creatures, but also larger forms, many of them injurious to plants, such as wire worms (millipedes) and the larvae of insects which damage roots, but on the other hand many perform useful service in helping to keep the soil porous and well aired. The earthworm, which may be a nuisance in connection with our lawns, is really a friend to agriculturalists in general, since it

(*Photo. Mr. H. James.*)

FIG. 57.—NODULES DUE TO BACTERIA ON THE ROOTS OF *a.* LUCERNE; *b.* BROOM; *c.* PEA; *d.* LUPIN.

turns the soil over by swallowing it and then discharging it again at the surface in the form of worm casts. Huge quantities of soil are thus turned over annually.

FERTILISERS, NATURAL AND ARTIFICIAL

In time a soil which was originally rich in nitrogenous matter and other potential plant food may become deficient and it becomes necessary to improve it.

Materials mixed with the soil to improve its condition are known as **manures** or **fertilisers**, and of these there are the natural

manures consisting of animal or vegetable matter, and the so-called ' artificial ' manures which include various chemicals such as sodium nitrate, calcium nitrate, ammonium sulphate, superphosphate, basic slag, etc. The most valuable of the natural manures is ordinary **dung** or **farmyard manure,** consisting of the waste products from various animals of a farm, and such manure is best when it is of a mixed character derived from horses, cows, pigs, and poultry. If plenty of this material were available, only the addition of some form of phosphate, such as basic slag, would be required to yield all the materials that plants require—nitrogenous matter, potash, and phosphate. But unfortunately the supply of farmyard manure falls far short of the demand, due largely to the replacement of horses by motor transport, even on farms themselves much of the work being done now by motor tractors ; hence the employment of great quantities of **artificial manures** or **fertilisers** in agriculture. Other forms of natural manure are obtained from decaying vegetation such as leaf mould, old grass cuttings, the residues of uprooted crops, etc., but these are mild compared with animal dung.

Farmyard manure when mixed with soils acts in three ways ; it increases the amount of plant foods, improves the physical condition or **tilth,** and keeps the soil warm as the result of fermentation, a fact that must not be overlooked, since the temperature has a considerable influence upon the rate at which most plants grow. Rotted manure which has been allowed to stand for some time is generally better than fresh, since the nitrogenous matter has already obtained considerable bacterial attention and more of it is in a form available as food. But not all of it is available at once, and it is an advantage to have part of the food rendered available some time after the application of the manure. This *delayed* effect is one of the chief properties of natural manure and is not found in connection with the chemical fertilisers, which are composed of material all available at the same time. One of the most valuable kinds of natural manure consists of the excreta of birds and known as **guano,** which collects as extensive deposits along the coast of Peru.

Continuous adequate supply of nitrogenous matter for plant life is very necessary, and the usual sources of nitrogen may

soon become exhausted, hence a serious 'nitrogen problem' has arisen.

Sodium nitrate or saltpetre is a natural mineral obtained from the ground in northern Chile, but even the vast supplies of this substance will eventually be exhausted; moreover, saltpetre is by no means suitable for all soils and crops. Within recent years successful processes have been established to 'fix' the nitrogen of the atmosphere by chemical means, and now large quantities of **calcium nitrate** and other nitrogenous fertilisers are produced by chemical means at Billingham and elsewhere. Another compound containing nitrogen is **ammonium sulphate,** now manufactured synthetically (see Chapter XXXVI) and produced as a by-product in the manufacture of coal gas. This, though soluble in water, requires considerable treatment from bacteria, and is apt to make soils 'sour' unless they are treated with lime periodically. Another substance termed **nitrolime** yields ammonia when treated with water in much the same way that calcium carbide yields acetylene when water is added.

In addition to nitrogenous matter, potash and phosphates are necessary, and in this respect soils differ a good deal, sandy soils often containing too little potash, while most soils, clay or sandy, require the addition of phosphates. The best potash fertiliser for most purposes is **potassium sulphate,** which occurs naturally as a mineral in Germany and is also manufactured.

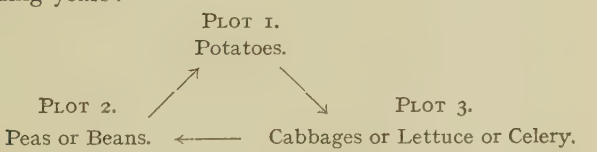
The natural mineral called **kainit,** also obtained from the deposits at Strassfurt in Germany, is a sulphate containing salt, too much of which is injurious to many plants, so that ordinary potassium sulphate is of more general value. The ash of burnt plants and wood is also valuable for its potassium contents.

The amount of phosphorus in soil is increased by the use of **basic slag,** which is a by-product in the manufacture of steel, and contains about 30 to 35 per cent. of phosphate. This material is best suited to wet clay soils, and another substance known as **superphosphate** is employed in the case of drier and more calcareous soils. Though not a manure in the ordinary sense, **lime** in some suitable form is immensely useful in agriculture. There are three well-known compounds of lime used for agricultural purposes—the carbonate, in forms known as

limestone and chalk ; the oxide, commonly called lime ; and the hydrate or slaked lime. Each of these substances is suitable for particular types of soil. Thus powdered chalk is generally used on sandy soil, but in all cases the results are similar ; the lime compound neutralises humus acids, helps to break up the soil, and makes the formation of calcium nitrate possible.

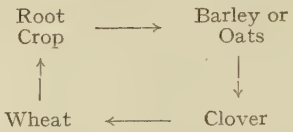
THE ROTATION OF CROPS

All plants are not alike as regards the depth to which the roots penetrate and the proportions of their food requirements, some needing more nitrogenous matter than others, some more potash, and so on. In certain cases, such as clover, peas, and beans, the ground is actually enriched by them as far as nitrogen is concerned, so that the next crop in the same ground reaps the benefit. If different kinds of crops having distinctly different food requirements are placed in successive years in the same plot of ground, the produce from that particular plot is much greater than if the same class of vegetable were placed repeatedly in it, and so exhausting the foodstuffs always in the same proportion. By proper observance of the **rotation of crops,** as it is termed, the maximum produce can be obtained from the soil, provided, of course, due attention is also given to manuring, etc. Many of us are concerned with getting the most from our kitchen gardens, and the following is an example of a very simple but effective three year garden rotation. This is the arrangement for the first year, and the arrows indicate the rotation of crops in the succeeding years :



Thus in the second year PLOT 1 should contain peas or beans, PLOT 2 should have cabbages or lettuce, and potatoes with good manure should be set in PLOT 3. Another shift all round occurs in the third year. A farmer being an agriculturist on a bigger scale is concerned mainly with crops not grown in kitchen

gardens, a typical four-course rotation consisting of root crops, then barley or oats, followed by clover, and lastly wheat.



Apart from the question of foods in the soil, rotations are valuable in other ways. Most diseases of vegetables are confined to particular kinds of plants so that a change of crop lessens the chance of disease being passed on to the next lot of vegetables set in the same plot of ground. Also, insect pests often live on a particular crop, so that a change gives them smaller chance of establishing themselves.

In **multiple cropping,** the same plot can be made to yield two or even three crops in the same year, a good double garden crop being early potatoes followed by brussels sprouts.

THE INFLUENCE OF WATER SUPPLY AND TEMPERATURE

The temperature of the ground, and of the air which touches it, is a very decisive factor of plant life. Generally, *plants thrive better in warm soil than in cold.* Now the amount of rain received at any place is largely determined by the temperature of the atmosphere—cooler air generally means more rain than that occurring with warm air. For special reasons, however, large quantities of rain are associated with certain hot conditions at some places within the tropics, such as the Amazon Basin. Therefore in going from the equator to the poles, the types of vegetation existing on land near sea-level gradually pass from typical tropical kinds through sub-tropical and temperate types to small mosses, etc. (alpine flora), characteristic of the far north.

When the land rises above sea-level, the type of plant life is modified *as if the place were in higher latitudes than it really is.* High mountain ranges near the equator, such as the Andes in South America, bear vegetation which slowly changes in type

from tropical at the foot of the mountains to small alpine plants just below the snow line (Fig. 58). Thus in crossing the Andes, a traveller as he ascends, passes through successive **vegetation zones** similar to those he would traverse if he were to travel on low ground from the equator to the Arctic Circle.

At the same latitude and altitude, plant types vary according to conditions of soil, water supply, temperature, and light, so that definite **plant communities** occur, each community consisting of plants which are suited to local conditions. Thus the collective

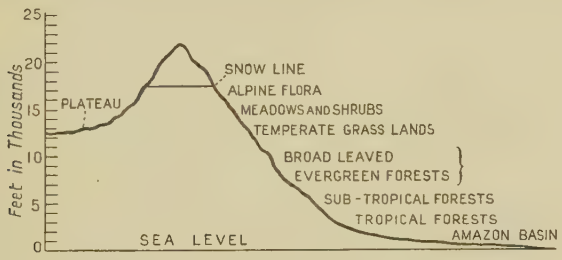


FIG. 58.

DIAGRAM REPRESENTING ZONES OF VEGETATION ON THE EASTERN SLOPES OF THE ANDES AT THE EQUATOR.

plant types or **flora** of meadows include various grasses, dandelions, plantains and others which can obtain a footing in spite of the grass which tries to monopolise the soil. On moorlands we find those kinds of plants, chiefly heather and gorse, which adapt themselves to exposed positions and to a limited available water supply; on low marshy ground there is an abundant flora, including marsh marigolds, marsh mallows, rushes, willows, and many others. Similarly woodlands, sandy coasts, and even rubbish heaps, support characteristic plant groups suited to the respective conditions. The study of plant communities, known as **ecology,** is rich in examples of plant adaptation to environment.

CHAPTER VII

INSECT LIFE AND ITS RELATION TO HUMAN ACTIVITIES

The various forms of animal life are exceedingly numerous, and in structure range from the simple **Protozoa,** such as *Amoeba*, to highly complex types culminating in the human species. There are two great groups of animals, the members of one group possessing a vertebral column or backbone, hence called **Vertebrates,** while those in the other group, the **Invertebrates,** have no vertebral column. The insects, the study of which is known as **entomology,** constitute one of the higher groups of the Invertebrata, higher, that is, in structure and mode of life, than members of many other invertebrate groups, such as corals, sponges, and sea urchins.

Nearly all insects are capable of flight, which has endowed them with greater abilities in food seeking and in finding suitable places for the hatching of their eggs and the development of their young. Thus endowed with superior powers of adaptation, it is not surprising that the number of known species in the group is more th n a quarter of a million. Geologically, the group is a very old one, insect remains being found in rocks deposited during middle Palaeozoic times,. some hundreds of millions of years before the earliest birds and mammals made their appearance. Fossil insects are usually found as impressions of wings, and from the study of these it is shown that the earlier types included ancestral forms of dragon flies, plant lice, bugs, and cockroaches, though true beetles did not appear until early in Mesozoic times, as did flies, ants, earwigs, and grasshoppers. Butterflies and moths appear to date from the Tertiary period.

Invertebrate animals that have jointed legs are known as **Arthropods,** insects forming a well-marked division of these since they possess six jointed legs attached to the middle part of the body. Each leg has several joints, and the last section often bears a pair of pincers or nippers, as in beetles and other carnivorous insects. Spiny processes, as in Mantis, assist in food capture, and a general hairiness of some insects, a bee's leg for example, happens to be particularly useful in the collection of pollen grains and the transference of these grains to female flowers in cross pollination.

STRUCTURE OF A TYPICAL INSECT

Examination of a housefly or a bee reveals the fact that the body of a typical adult insect (Fig. 59) consists of three distinct portions—head, thorax, and abdomen. In many cases, particularly beetles, the head is embedded in the thorax, but in others, such as bees, wasps, and flies, the three portions of the body are joined by very slender connections.

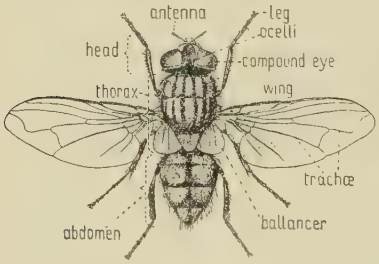


FIG. 59.—HOUSEFLY, WINGS EXTENDED.
(By courtesy of the Director, British Museum: Natural History.)

The **head** bears the organs of vision, the 'feelers' or jointed **antennae,** and the structures corresponding to the mouths of larger animals. There are usually two large **compound eyes** separated by a space which is, in the housefly, broader in the female than in the male. As a rule the compound eyes are each composed of some thousands of minute lenses, so that the image formed by them must be a multiple picture quite unlike anything which we ourselves experience. There are also smaller simple eyes or **ocelli,** usually three in number, arranged like a triangle and situated more towards the middle and top of the head. The antennae vary considerably in length, being relatively short in the

house-fly and long in lacewings; sometimes they are smooth, in other cases hairy.

The mouths of insects usually possess a pair of upper jaws and another pair of lower jaws, the movements of such jaws being sideways, somewhat like the action of scissor blades, but the mouth structures vary according to the kind of food consumed. In general, mouths are adapted either for biting, as in beetles, or for sucking, as in flies, butterflies, and moths. Often the mouth is so small that only liquid food can be taken, and this is sucked up by means of a tubular structure called a **proboscis,** which in a housefly can be folded away when not in use. On the other hand, the larger stable fly, a different species, has a *non-retractable* proboscis which cannot be tucked away. In a bee the proboscis is used for collection of the honey-like nectar of flowers. Large numbers of insects are carnivorous and feed upon other insects, but many feed upon plants, as in the case of the Aphides or plant lice, which suck the sap of rose trees, etc. Cockroaches eat both animal and vegetable matter.

Next to the head is the larger portion of the body called the **thorax.** All of the six **legs** are connected to this, so are the **wings,** usually four in number, though in the housefly and many others the pair nearer the abdomen are very much reduced and known as 'balancers.' A few primitive types have no wings at all.

In insects there is no breathing organ comparable with the lungs of higher animals, but respiration is carried on by means of a network of tubes or **trachae** which extend all over the body and communicate with the outside air through pores situated between the segments or divisions of the body. In the wings these breathing tubes appear like a system of veins and the patterns formed by them are of use in classification. Alternate expansions and contractions of the body cause air to circulate through the trachae. There is a rudimentary cylindrical or sausage-like heart concerned with the distribution of a nearly colourless blood which moves freely in the body, that is, it is not confined in blood vessels.

The **abdomen** usually consists of nine horny ringed segments

or divisions, and does not bear any appendages or external structures except the stinging apparatus of bees and wasps, or the forceps-like structures in earwigs. Some animals have no definite **nervous system,** but insects possess central nerves extending along the body and having usually eight centres or **ganglia** from which smaller lateral nerves proceed (Fig. 60). In spite of the simplicity of this nervous structure, which is all that represents the complex system and brain of higher animals, many insects exhibit greatly developed instincts and some intelligence; particularly is this the case in ants, bees, and other social insects which live as organised communities.

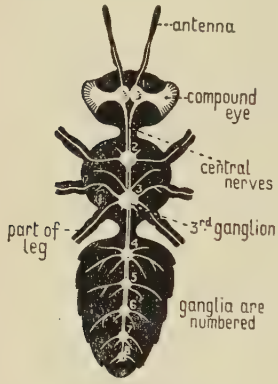


FIG. 60.—THE NERVOUS SYSTEM OF A BEE.

INSECT METAMORPHOSIS

The structures we have just considered are those of a complete or *mature* insect. A lamb is very obviously a miniature sheep, similarly a chick though small resembles its parent, but a young insect is nearly always quite unlike the creature it becomes in later life. The silk moth (*Bombyx Mori*) is a well-known example which will serve as an illustration of the changes in form that an insect undergoes during its development. The female moth lays some 300 pale coloured disc-like **eggs** and dies soon afterwards. From each egg, on hatching, there emerges a light coloured hairless caterpillar or **larva,** and this part of the creature's existence is known as the *larval stage.* This is the period of growth, the insect being very voracious, devouring many leaves, and storing up food material for the later stages characterised by development, not growth. The silk 'worm' attains a length exceeding two inches, casts its skin four times, and at the end of about four or five weeks spins a cocoon of silk

thread around itself and becomes a much less active and dark coloured **chrysalis** or **pupa.** On both larva and pupa the openings of the trachae are indicated by little round dots, but in most ways these earlier forms appear very different from the final product, the **moth.** At the end of another two or three weeks, a pale ashy moth, the perfect insect or **imago,** emerges from the chrysalis and the cycle of events is complete. These successive changes in form are known as **metamorphosis,** and the complete series of events which occur between the hatching of the egg and the death of the adult imago is called the **life history** of the insect (Fig. 61).

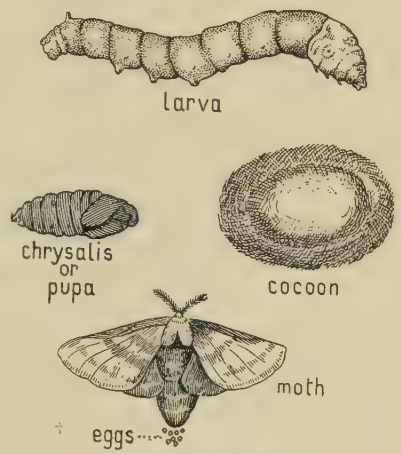


FIG. 61.—METAMORPHOSIS OF THE SILK MOTH.

Most insects pass through the stages — egg, larva, pupa, and imago, so that their metamorphosis is said to be complete, but in some cases there is not so much difference between the earlier and later stages of development, when the metamorphosis is said to be incomplete. Cockroaches, plant lice, bugs, locusts, grasshoppers, and earwigs are examples of insects having incomplete metamorphosis. There are many insects in which the earlier stages are adapted for a life in water though the later imago is fitted for existence in the air, dragon flies and mosquitoes being examples. There are others, such as the common water beetle, in which all stages are adapted to an aquatic life.

The metamorphosis of the silk moth is typical of normal insect development, even the spinning of the cocoon being a feature shown by many other insects; it is the *quality* of the silken fibre that has made this little creature a benefactor to mankind. The silk is secreted as a yellow fluid by two glands, one on either side of the caterpillar, and both glands lead to an opening known

as a **spinneret.** As the fluid emerges from the spinneret it becomes solid, and a single larva may spin as much as 1200 yards of silk. If the pupa is allowed to change into a moth the cocoon becomes damaged because the moth eats its way out. Therefore in countries where the silk-worm is cultivated on a large scale for the production of silk, the chrysalides are destroyed by steam, only a few being permitted to complete the life cycle for the sake of the eggs, and in these cases the silk is removed. The cultivation of this insect has proceeded in those countries where mulberry trees are numerous, since the leaves of this tree are the best kind of food for the larvae. The silkworm industry originated in China some forty centuries ago, and thence spread westwards via Constantinople into Southern Europe.

MOTHS, BUTTERFLIES, BEES, AND RELATED INSECTS

Moths and butterflies belong to the division of insects known as **Lepidoptera** (=scale wing), since their wings, often highly coloured and of very varied shapes, are covered with scales. Butterflies are distinct from moths in having club-like terminations on their antennae. Many of this group are injurious, a well-known example being the White Cabbage Butterfly, the pale green larvae of which makes such havoc with cabbage leaves. Similarly the large caterpillar of the Hawk Moth devours potato leaves, the larvae of the Apple Moth feed on apples, those of the Magpie Moth attack blackcurrant and gooseberry bushes, while the Tineae include the small clothes moths which lay their eggs in clothing, the larvae later making holes in the fabric.

The great majority of insects are enemies of man, either destroying his crops or carrying disease to him or to his domesticated animals, but the honey bee, a member of the **Hymenoptera** (=membrane wing), so called on account of their thin transparent membranous wings, is useful to man for the production of wax and honey.

The general anatomy of the complete bee (*Apis mellifica*) has already been described, but one or two additional features must be noted. There are four gauzy wings, the hinder pair smaller

than those in front and fixed to them, while in flight, by means of a series of minute hooks. This arrangement ensures the proper vibration of the wings in unison. At the end of the abdomen the **stinging apparatus** is situated (Fig. 62), and consists of a barbed sting protected by a sheath, and connected to a glandular arrangement which secretes the poison. The barbed nature of the sting means that it can be used once only, as on that occasion it is detached from the body and causes the bee's death. The males are not provided with a sting.

The bee's proboscis, a hollow, tongue-like structure, is used for sucking the sweet fluid nectar from the nectaries of flowers. This

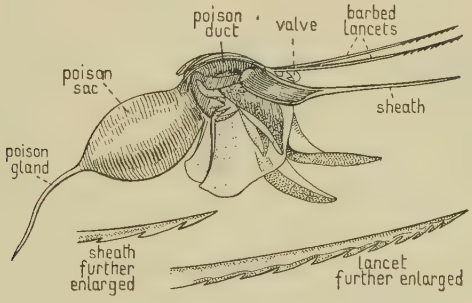


FIG. 62.—THE STINGING APPARATUS OF THE HONEY BEE, GREATLY ENLARGED.

substance passes from the proboscis into a small honey bag within the bee where it undergoes certain changes so that when it is later discharged into the waxen chambers within the hive, it has become honey. Pollen mixed with honey forms the food intended for the larvae hatched from eggs laid by the queen bee.

In its life history the bee passes through the usual stages; its metamorphosis is complete. Each egg has a waxen cell to itself, and produces a smooth, legless larva which grows for a time and then spins a cocoon and becomes an immovable chrysalis in which the parts of the bee can be seen more clearly than in the larva. About twenty days after the laying of the egg the imago or bee emerges from the chrysalis.

Apart from the collection and preparation of honey, bees are particularly interesting because of their *social habits*. In a

community there are three classes of bees (Fig. 63), the female or **queen bee,** the **workers,** and the males or **drones.** The queen is concerned with the production of eggs, a small number of special ' royal ' eggs being placed in special cells and developing into new queen bees later on. Only one queen can be tolerated in a hive, so that when these royal princess bees reach maturity, the old queen pairs with a male, goes off with a swarm of workers and founds a new colony elsewhere. One of the royal princesses becomes queen and her sister princesses are murdered. The workers, sometimes described as **neuters,** but really imperfectly developed females, are the mainstay of the bee organisation.

FIG. 63.—THE THREE TYPES OF HONEY BEES INHABITING A HIVE.

While some are making wax, which is secreted on the under side of their bodies, and with it construct the honeycomb composed of many six-sided chambers, others are collecting nectar and preparing honey, and still others are attending to the needs of the larvae. As we have seen, many cells are used for the rearing of the young insects and others are put aside for royal bees, but some are employed as receptacles for the storage of honey really meant for the young bees but, as in many other cases, appropriated by man for his own use. The wax is also a useful substance.

Though the workers only live for a few months, a queen bee may live from three to five years. The males or drones are slightly larger than the workers, their function being that of fertilisation of eggs laid by the queen. They do no work, and at the end of the summer when food supplies are running short they are killed by the workers which, though smaller, are far more powerful, since the drones have no stinging apparatus.

There are other bees besides those concerned with honey, the

large ' bumble bee ' being a different species, so also is the solitary leaf-cutting bee. Certain insects assume an appearance similar to that of a more formidable species as a means of defence, such **mimicry** being illustrated by the Drone Fly, which appears very much like a bee though it is really a harmless fly.

Wasps are in many respects similar to bees. They have stings, often build honeycomb-shaped nests, but of vegetable fibre not wax, and some of them prepare a poisonous substance analogous to honey. The common English wasp and the Hornet, a larger type, are social insects, and like the bees consist of females, males, and workers. Though they act as scavengers, they are mainly a nuisance and many of their larvae are destructive to the leaves of trees.

Other social members of the Hymenoptera are the **ants,** which lead a communal existence as well organised as that of bees. Here again there are developed females whose main duty is to provide for the continuation of the race, males, and undeveloped wingless females, the workers, which construct underground habitations, collect food, and attend to the young. The workers also lay eggs, but these produce only males, all females whether queens or workers coming from eggs laid by the queen ants. Some of the workers having very large heads are known as **soldiers.** In the process of metamorphosis, the eggs yield small white larvae which later spin cocoons and become white pupae, from which the perfect insects are ultimately set free.

It is unfortunate that a group of creatures so capable and so well organised should be harmful. In tropical countries they are so numerous as to be a plague, and their activities in collecting leaves etc., for construction of their subterranean galleries does great damage to vegetation. These dark coloured ants must not be confused with so called **white ants** or **termites,** which are not really ants but belong to the **Neuroptera** (=nerve wing), a division of insects including dragon flies and May flies. The termites are characteristic of hot countries, build large hills, often sixteen feet high or more, and they are a greater nuisance than the true ants, often reducing wooden structures to the condition of mere shells. Teak is one of the few timbers which can withstand their attack.

One or two other species of Hymenoptera must be mentioned. The **Ichneumon flies** deposit their eggs inside the caterpillars or larvae of other insects, particularly those of butterflies and moths. This is done by the egg-laying structure or **ovipositor,** which punctures the skin of the victim and lays the eggs therein. The Ichneumon larvae presently develop and feed upon the substance of their host, which is thus destroyed. As a contrast to this good work is the deposit of eggs by the **Gall flies** in young oak trees, leading to the formation of **oak apples.** These swellings, called galls, are due to an irritant fluid deposited at the same time as the eggs. An Ichneumon fly may even pierce these galls and deposit an egg inside the gall fly larva within. Another fly, the **Fir-Wood Borer,** has a long ovipositor by means of which she bores a hole in fir trees and lays her eggs there, with the result that the larvae do great damage by making long burrows in the wood.

THE HOUSE FLY (*Musca domestica*)

Flies having two large wings are included in the group of insects called **Diptera** (=two wings). As explained earlier, the housefly really has four wings but two of them are so small as to be ineffective as organs of flight. In this group are also included gnats or mosquitoes, daddy longlegs, and fleas, the last having only rudimentary wings, so that their legs have become very strong and adapted to jumping.

The main facts concerning the life history of the housefly and its relation to disease are of extreme importance to mankind. The female fly, or rather flies, since many of them like to lay their eggs at the same time and in the same place, deposits her white eggs in fresh stable manure or, failing that, in household rubbish (Fig. 64). The fly will not use an old manure heap unless fresh material has been added to it. In warm weather the eggs change to white larvae or maggots in about twenty-four hours, but two or three days are necessary if the weather is cool. In circumstances favourable to growth, the white legless maggots are fully grown and measure about half an inch at the end of four or five days. The maggots then change into pupae which become darker in colour as the time approaches for the

mature fly to emerge. The length of time taken by the changes from larva to pupa, and from pupa to fly, is determined mainly by the temperature ; in cool weather the pupa stage may last three or four weeks though in warmer conditions only a few days are necessary. When the larvae are about to change into pupae they usually seek some cooler spot in the soil away from the manure heap in which to complete their metamorphosis. Some-

FIG. 64.—LARVÆ OF HOUSEFLIES IN MANURE.
(By courtesy of the Director, British Museum : Natural History.)

times the brownish pupae are found behind loose wallpaper or in other odd places.

By reason of the materials in which the eggs are deposited, it is not surprising that the *housefly is a deadly carrier of diseases, among which are cholera, typhoid fever, dysentery, and summer diarrhoea.* Flies pass from manure heaps (particularly in insanitary country districts) direct to food meant for human consumption and carry germs of disease on their feet and on the hairy surfaces of their bodies. They also swallow refuse and eject it again as excreta, the evil effect of which is obvious.

The best means of prevention of this germ distribution is the improvement of sanitation, particularly in rural areas. Stable and farmyard manure heaps should be turned over frequently, so that the eggs deposited near the top are then at the bottom and, being there subjected to greater heat of fermentation, are likely to be destroyed. Household refuse should be kept covered, and ash bins emptied frequently, while articles of food should be adequately covered, and fly traps used extensively. The extent of the danger may be realised from the fact that one female may deposit about 900 eggs during its lifetime of a few weeks.

MOSQUITOES

The Diptera are particularly obnoxious in providing us with unwanted germ carriers. The small insects we call gnats are really **mosquitoes**, but the dangerous members of this group are chiefly found in tropical and sub-tropical countries. Certain mosquitoes belonging to a group named *Anopheles* are the carriers of malaria, while another, known as *Stegomyia fasciata*, is responsible for the spread of yellow fever. Other species are connected with the tropical diseases known as elephantiasis and dengue fever.

FIG. 65.—A MOSQUITO: *Anopheles maculipennis.*

Female. This mosquito is the principal malaria carrier in Europe.

Photo, by J. F. Marshall, Director, British Mosquito Control Institute, Hayling Island, Hants.

As is usually the case, the female mosquitoes are the source of trouble, since the male is not a blood sucker and lives upon the sap of plants. The larvae of mosquitoes are small 'wrigglers' which live in water, though they have to come to the surface to breathe (Fig. 66). These ultimately change into pupae, but, as in the case of house-flies, temperature and moisture conditions determine the length of time required for the change

into the complete insect. It may take only a few days or it may require months. Unlike most chrysalides, those of mosquitoes are very active and soon change into the complete insect, merely a few days being sufficient. Some mosquitoes lay their eggs on water and others in dried-up ditches where water collects in winter.

Malaria and yellow fever are due to blood parasites carried by mosquitoes from one person to another, and in both diseases the parasite *must* enter first a mosquito and then a human

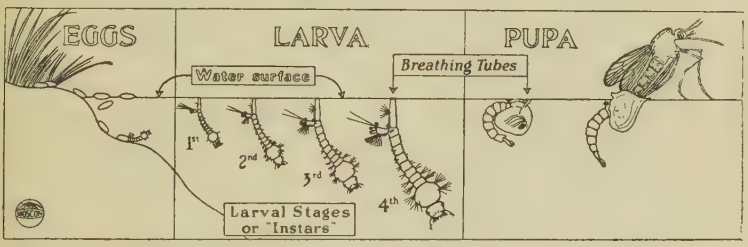


FIG. 66.—THE METAMORPHOSIS OF A MOSQUITO,
FROM THE EGG TO THE COMPLETE INSECT.
(*Diagram by J. F. Marshall, Director, British Mosquito Control Institute, Hayling Island, Hants.*)

being in order to complete its own development. Medical researches on mosquitoes and disease are mentioned in a later chapter.

THE FLEA (*Pulex irritans*)

Though fleas have only rudimentary wings, they are classed with the Diptera. There are other differences between flies and fleas, the latter having both head and abdomen embedded in the thorax, while the eyes are much less developed than in flies, some species of fleas being blind. The body of a flea is tall and thin, as if it had been compressed from the sides, and in this respect it is rather unusual. The lip and jaws of this insect are long, narrow, and like a saw, and when they interlock they form a tubular structure through which blood is sucked from a victim.

In proportion to its size a flea has a large stomach, and when the

insect is infected with the bacilli or germs of the horrible disease called bubonic plague, the stomach eventually becomes choked with the bacilli (Fig. 67). In this condition the thirsty flea sucks blood towards the stomach at the entrance of which it mixes with the bacilli and is then discharged back into the wound in the victim, who will probably develop plague in consequence. The disease develops in rats, and then infects fleas, particularly the Asiatic rat flea, which carry the disease to man. Though hundreds of different species are known, eleven kinds are capable of transmitting plague, five of these being British types.

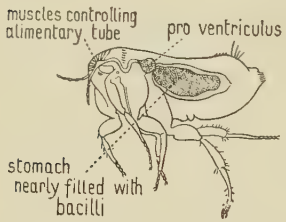


FIG. 67.—A FLEA IN AN ADVANCED STAGE OF DISEASE DUE TO GERMS OF PLAGUE.
(By courtesy of the Director, British Museum: Natural History.)

In their life history fleas pass through the usual stages of metamorphosis (Fig. 68). Oval waxy-looking eggs develop in about ten days into white bristly, legless and blind larvae. These spin cocoons and change into chrysalides which yield the perfect fleas often quite suddenly on account of vibration or other disturbance. Eggs are usually laid upon the bodies of the hosts —rats, mice, squirrels, etc. It is a strange fact that whereas some fleas prefer the blood of mammals, others will take only that of birds, and so on.

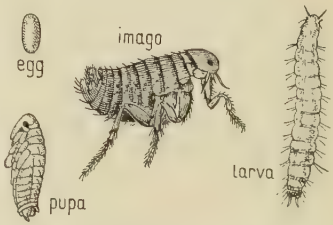


FIG. 68.—METAMORPHOSIS OF THE COMMON FLEA.
(By courtesy of the Director, British Museum: Natural History.)

BEETLES AND COCKROACHES

While the Diptera exert their evil influence in connection with disease, many of the **Coleoptera** (= sheath wing) or beetles, attack our plant foods or reduce timber to the condition of a sponge

by the burrowing habits of their larvae. In this group the metamorphosis is complete. In a typical beetle the front pair of wings are composed of a horny substance called **chitin**, and are known as **elytra**, their function being that of protection for the hind wings, which are the only ones which move during flight. The head is embedded in the thorax and possesses jaws adapted to a carnivorous diet, though many eat leaves of oak trees, etc., the common cockchafer being one of these. Another species, *Zabrus*, eats ears of corn, but often it is the larvae which causes most damage.

The destructive work of various larvae include the formation of 'worm' holes in furniture by a species called *Anobium*, the riddling of woodwork by larger types such as *Xestobium*, the destruction of apples by the small apple weevil and of the vine by the vine weevil. Other weevils attack corn, coconut palms, oak and birch leaves, and pine trees, while the potato beetle is a serious pest in connection with potatoes. It would be indeed a long list which included all the varieties of Coleoptera which are our enemies, but there is nearly always an exception, and in this case there is the little scarlet ladybird, one of the best friends of the gardener, since it eagerly devours the aphides or plant lice found on rose trees and other plants. A few, such as the carrion feeders or *Necrophaga*, also do good in disposing of dead frogs, mice, birds, etc.

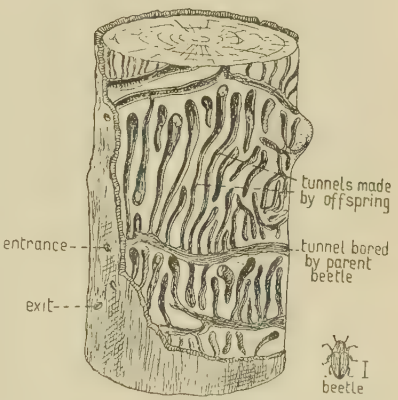


FIG. 69.—PART OF A TREE RIDDLED BY A BEETLE AND ITS LARVAE.

It must be noted that the ordinary cockroach is not a beetle but belongs to another order, the **Orthoptera** (=straight wing), in which the metamorphosis is incomplete. This order also includes grasshoppers, crickets, locusts, and earwigs. Cockroaches are both loathsome and destructive. The males have

small wings but the females are wingless and lay their eggs in cases, about three dozen eggs in one case. The most destructive of the whole group are the migratory locusts which descend in swarms upon cornfields, etc. in tropical and subtropical countries, and in a short time the whole of the vegetation is destroyed. The related grasshopper is a comparatively harmless creature which makes a chirping sound by rubbing its legs against the wings. In the crickets the sound is caused by one wing rubbing another.

There are other orders of insects which cannot be described here, but enough has been said to show how great a power for evil is this group of animals. One or two are helpful, but if an estimate of insect work is drawn up, there is an enormous adverse balance far outweighing any good that the honey bee, the silk moth, or the ladybirds do for us. But it must not be imagined that no headway is being made in the control of insect pests. In New Zealand, Australia, California, and elsewhere, certain other insects which destroy various pests are being cultivated and then liberated in great numbers to wage war against the pests. An example that has attained considerable success in New Zealand is *Aphelinus*, a species of wasp, which has kept the apple-tree pest, called woolly aphis, under control. Attempts are being made to introduce insects which will effectively control other aphides, earwigs, pear slugs, and many other injurious creatures. The good work done by cultivated insects is not restricted to the destruction of other insects, for successful work is also being done in the destruction of noxious weeds. One of the most widespread injurious plants of Australia is the prickly pear, and this is now being attacked by the cochineal insect and related species, which have been imported from California, where they are an important natural agent in controlling the spread of prickly pear.

CHAPTER VIII

SOME INHABITANTS OF SEA, RIVER, AND POND

THERE is little doubt that Life originated in the sea. The development of limbs and of lungs are examples of adaptation to life on shore, and it is generally believed that the ancestral amphibia, a group now represented by frogs, toads, and newts, were the first to make the great change from an aquatic to a terrestrial life. At the present day, after hundreds of millions of years of organic evolution, the sea is still the habitat of the great majority of invertebrate animals and of fish, the lowest division of the vertebrates.

SIMPLE MARINE ORGANISMS

Marine invertebrate types range from Protozoa to the cuttle-fish and nautili. An interesting example of the Protozoa is *Noctiluca*, which is a cause of phosphorescence in the sea at night, though in the daytime, even in a darkened room, the phosphorescence is not noticeable. Enormous numbers of minute organisms, collectively known as **plankton**, live near the surface of the sea, and where they vary in numbers according to seasonal changes, in temperate latitudes they are more numerous in summer. Characteristic of late winter and again of autumn are the myriads of tiny plants called **diatoms** (Fig. 70), the ultimate source of food for most marine animals. These organisms secrete an enclosing shell-like structure made of silica or flint, and on their death the minute shells sink to the ocean floor, forming there a widespread deposit called **diatom ooze**. Small floating animals which similarly secrete siliceous shells are the **Radiolaria**, and a number of **Foraminifera** construct calcareous or limestone shells. A constant rain of

these shells upon the ocean bed produces Radiolarian and Foraminiferal oozes respectively (see *Globigerina*, Chapter III).

More advanced organisms living near the surface of the sea on the crests and peaks of submerged mountains are the **coral polyps,** animals having a definite body cavity for food digestion, and in outward appearance somewhat similar to small sea anemones found in pools along the English coasts. But whereas the anemones are wholly soft and jelly-like, the coral polyps secrete calcareous plates which remain after the death of the organism and consequent decay of the soft parts. Corals may

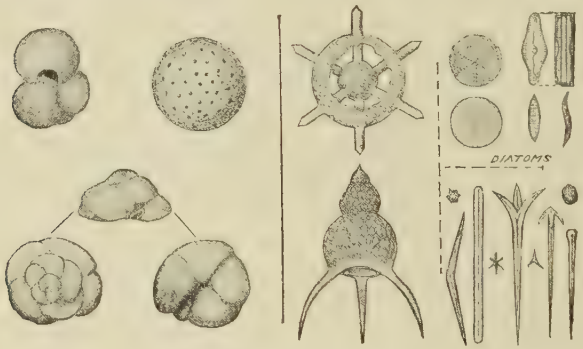


FIG. 70.—FORAMINIFERA, RADIOLARIA, DIATOMS, AND SPONGE SPICULES.

be simple, that is solitary individuals, or may occur united together in immense colonies which form coral reefs, the white and pink skeletal structures of which constitute the coral of commerce.

Modern reef-building corals are found to require certain conditions of temperature and pressure. They can thrive only in warm, shallow, and clear salt water, and if the assumption that reef builders of former geological periods required similar conditions is legitimate, the presence of extensive reef material in the Carboniferous and other limestones yields considerable information concerning the climate, depth, and condition of the sea existing at the time of deposit.

The harder of these old coral limestones take a good polish

and form excellent ornamental stone, the well-known Derbyshire marble being a very fine example. The Torquay limestone of South Devon is another, but the yellow Corallian limestone found around Oxford is much less durable, a fact which accounts for the crumbling surface condition of some of the old buildings in that famous city.

(*Photo by W. Saville-Kent.*)

FIG. 71.—A CORAL REEF, OUTER BARRIER, AUSTRALIA.

Sponges are simpler animals living as separate individuals on the sea floor, and there are others which inhabit fresh water. The bathroom sponge, found in the Mediterranean, is a skeletal structure made of the horny substance called **chitin,** of which our finger nails and hair are also composed. During life the chitinous skeleton supports a mass of jelly-like material having innumerable channels termed canals, and the movements of small hair-like structures, or cilia, cause streams of food-bearing water to pass through the sponge. In other sponges the skeletal framework is composed of minute needle-like bodies called

spicules (Fig. 70), which may be composed of either flint or limestone. It is obvious that such types of sponge are unsuited to domestic purposes.

Flint nodules of various shapes and sizes are found in the Upper Chalk of England and elsewhere, and it is generally believed that this siliceous material was originally in the form of sponge spicules and Radiolarian shells, and that these organic structures were dissolved in the sea water and then re-precipitated in nodular forms. Economically this substance is of great importance, being powdered and used in the manufacture of china, porcelain, and flint glass. The nodules are often employed as road metal or as building material, while in prehistoric times primitive man acquired great skill in shaping his knives, arrow heads, and skin scrapers from them.

It should be clearly understood that when we speak of the skeletal structures of sponges and corals, we do not mean that they are in any way comparable with the skeleton or backbone of a vertebrate animal. Many invertebrate animals secrete a calcareous shell or covering mainly for protective purposes, and these shells may consist of two parts hinged together as in **bivalves,** or may be all in one piece as in snails and other gasteropods. In all cases the calcareous material is obtained from salts dissolved in sea water and replenished by dissolved limestone carried from the land by rivers. Most sandy beaches are strewn with disconnected valves or shells of marine molluscs ; the **oyster** of commerce is an example of a well-known mollusc. The edible oyster (*Ostrea edulis*), is found in English waters, principally the estuary of the Thames, at Whitstable and Brightlingsea. Many millions of oysters are consumed annually, and the industry is protected by legislation making it illegal to sell oysters during the breeding season between May 15 and August 4. The **common mussel** is another bivalve used as an article of diet.

The calcareous matter of shells is secreted layer upon layer, and should such a deposit occur around some irritating nucleus between the fleshy part and the inner surface of the shell, a rounded growth of concentric layers is formed. In the pearl oyster, an inhabitant of the Indian ocean, these growths, or **pearls,** are perfect in form and are composed of that variety of

calcium carbonate known as aragonite. The most important pearl ' fishery ' is in the Persian Gulf.

CRUSTACEA

Most creatures of the sea which are of value to us are used as articles of diet, an important group of such animals being the **Crustacea,** another division of the Arthropoda, since they, like insects, have much jointed legs. The group includes lobsters, crayfish, crabs, shrimps, prawns, barnacles, and woodlice, all of

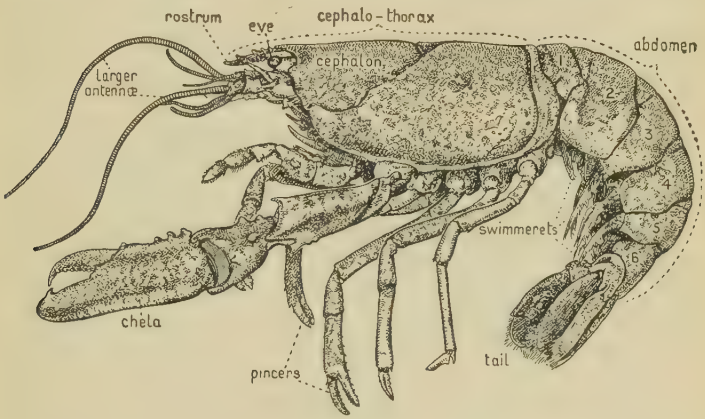


FIG. 72.—THE COMMON LOBSTER.

them possessing a hard outer crust or covering giving the name to the group. The **common lobster** is caught in large numbers, particularly in the summer months when many thousands are delivered every day at Billingsgate Market in London. The smaller crayfish found in rivers is structurally very similar, so that a broad general description of a lobster will apply to both. The main portion of the body is composed of the **cephalo-thorax** (Fig. 72), so called because it contains the head or *cephalon* embedded in the thorax, and the abdomen, which has six jointed segments and a fan-like tail. The two compound eyes are borne on little stalks and protected by the projecting *rostrum*. Below the eyes are situated two pairs of antennae, one pair long, the

other short. Lower down are the small mouth and the jaws. Attached to the cephalo-thorax are five pairs of jointed legs, the first pair bearing huge pincers or *chelae*, the second and third pairs also having smaller pincers in true lobsters; in this respect the true lobster differs from the so-called Spiny Lobster which has no pincers on these legs.

Most of the abdominal segments are furnished with appendages called *swimmerets*. The whole calcareous armour is continuous though thinner and flexible at the joints. The rigid nature of this casing necessitates periodic changes so that the animal can increase in size. When a lobster moults, it emerges completely from its shell which is cast aside whole; the new shell formed within the old one is soft and adjustable at first, but soon hardens.

The structure and arrangement of the internal organs of the lobster are fairly complicated, but since similar organs or their equivalents recur in many other animals described later, it is as well to make a preliminary consideration of organs and functions here, without too much detail.

It may be said of most animals, at this or higher stages of complexity, that they possess a few systems of organs, each concerned with some process vital to the living organism as a whole.

In the *circulatory system* of the higher animals, a contracting and expanding muscle, the **heart**, pumps blood through the arteries and vessels so that it can be brought into contact with all the cells of the body; the blood carries nourishment to the cells, brings oxygen to them whereby chemical changes are initiated yielding energy for the life processes of the cell, and removes carbon dioxide and other waste products which are formed.

The *respiratory system*, or means by which the process termed breathing is carried on, enables the blood to renew its supplies of oxygen and to discharge the carbon dioxide it gathers up during its journey through the body tissues. Quite as important is the *digestive system*, the function of which is to prepare food in the **stomach** so that it is properly absorbed or digested in the **intestine.** Digestion of food is necessary for the maintenance of vigour at all periods of life and for the increase

of bodily material required for growth during the immature stages.

The sense organs or *nervous system* enables an animal to see and feel its prey, to control the movements of its limbs and body, and to correspond with its environment in other ways, such as smell, taste and hearing. The nervous system is associated with instinct and intelligence, which are based on sense experience.

In lobsters, as in fish, the breathing or **respiratory organs** consist of **gills**, not lungs, since the latter are quite unsuited to respiration in water. The gills consist of thin plume-like membranes containing blood-vessels which permit oxygen dissolved in the water to pass by osmosis through to the blood, and the carbon

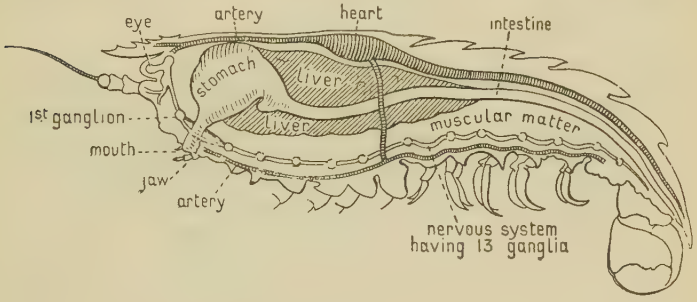


FIG. 73.—THE INTERNAL ORGANS OF A LOBSTER.

dioxide to pass out from the blood to the water. Fig. 73 being a section through the middle, does not show the gills, which are at the sides of the head. The elongated heart pumps nearly colourless blood to the gills through a system of arteries which divide into smaller vessels called capillaries.

The main parts of the **digestive system** include a sac-like stomach, a long intestine and a large liver, which is a gland secreting digestive fluids passed into the intestine in order to assist in the process of food digestion.

The **nervous system** consists of a chain of thirteen pairs of ganglia or nerve centres connected by nerves extending along the body and sending out nerves in other directions. The two larger ganglia nearer the eyes are the most important and control the greater part of the animal. Though no special organ of

taste has been found, a lobster smells and hears, the organ corresponding to ears being situated in the basal joint of the smaller antennae or antennules. The remaining parts of the body are composed of muscle, which forms the edible portions. The organs of reproduction are very similar to those of many other animals, the young being derived from eggs.

In general structure, **shrimps** and **prawns** are very much like lobsters on a small scale. Shrimps when boiled are brown, but prawns are pink and of a larger size. The common shore crab is so built as to resemble the product which would be obtained if lobsters could be stretched sideways and contracted lengthways. There are other differences, the most noticeable being the very short antennae in the crab.

Among the higher invertebrates are the Cephalopoda (=head footed), which include the cuttlefish, *Octopus*, *Nautilus*, and the extinct *Ammonites* and *Belemmites* found as fossils in rocks of Mesozoic age. The common cuttlefish or *Sepia*, which is not a fish at all, has two large eyes, and a beak-like mouth surrounded by two long arms or tentacles and eight shorter ones, all supplied with suckers. There is no outer shell as in *Nautilus*, though there is a soft white porous internal 'bone.' A characteristic feature is the 'ink sack' or gland which secretes the pigment called sepia used by artists. This fluid is ejected into the water, so darkening it, and forming a protective screen around the animal.

FISHES

A serious weakness in the geological record consists of the absence of evidence concerning links connecting the invertebrate animals with the vertebrates. Fossil primitive fish-like creatures are found in early Palaezoic rocks, but these remains consist merely of skin armour which belonged to creatures lacking a lower jaw and paired fins, the latter in fish corresponding to the limbs of land animals. A vertebral column, if such existed, must have been very soft and incapable of fossilisation. Even at the present time there are two main groups of fishes, the **Elasmobranchii**, which have vertebral columns composed only of cartilaginous matter or gristle, and the **Teleostei**, which possess

true bony vertebrae. Sharks and-dog fish, types we could very well do without, are examples of the elasmobranchs, while the great majority of edible fish—salmon, trout, plaice, herrings, and a host of others are members of the Teleostei. The earliest remains of true fishes are found in an old formation called the Silurian, the elasmobranchs coming on the scene a little before the others. In addition to the cartilaginous skeleton, primitive features exhibited by modern elasmobranchs include the absence of a covering for the gills, and a *heterocercal* tail, that is, one composed of two lobes of unequal size.

The general structure of a typical bony fish may be understood by consideration of a well-known example, the **trout**

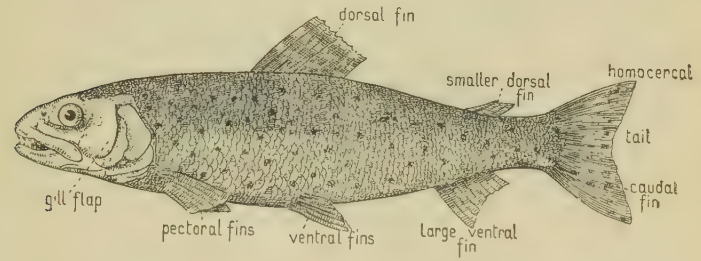


FIG. 74.—TROUT
SHOWING THE ARRANGEMENT OF FINS AND SURFACE MARKINGS.

common in our rivers and lakes (Fig. 74), but the family is by no means confined to fresh water, since some varieties are found in the sea. The body of the trout is elongated and graceful, has no neck, and is terminated by a *homocercal* tail, *i.e.* one having two equal lobes (Fig. 74). The head portion contains large eyes without lids, nostrils connected with the sense of smell but in no way connected with breathing, a wide mouth furnished with pointed teeth, and the respiratory gills, which are protected by a flap. The process of breathing is performed without effort ; a current of water enters at the mouth, passes over the gills and emerges at the gill slits. A fish looking upstream with its mouth open has the necessary work done by the current of river water. The sense of hearing is experienced by means of an

internal ear or labyrinth corresponding to our own inner ear structures.

On the body there are various projecting membranous structures called **fins,** in most of which the membranes are supported by bony rays which are not attached to the vertebral column. Fins vary in number, size, and position in different fishes, those in the trout consisting of a large caudal fin, commonly called the tail, a pair of pectoral fins, another ventral pair, a larger fin nearer the tail, and on the upper or dorsal surface a large dorsal fin, and a smaller one having no bony support.

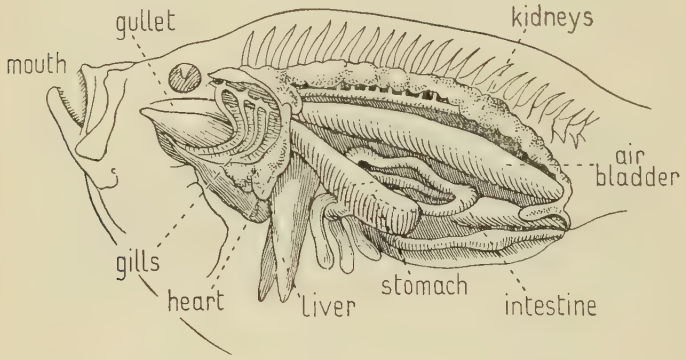


Fig. 75.—Chief Internal Organs of a Fish (Perch).

The functions of fins are connected with locomotion and balance, the caudal fin being the chief means of propulsion through the water, while the pectoral fins act as a brake checking, when necessary, the creature's speed. The other fins preserve the general balance. The body is covered with small grey scales kept smooth and slippery by a slimy substance excreted through pores along each side of the fish. Numerous red spots are characteristic of a trout's external ornamentation.

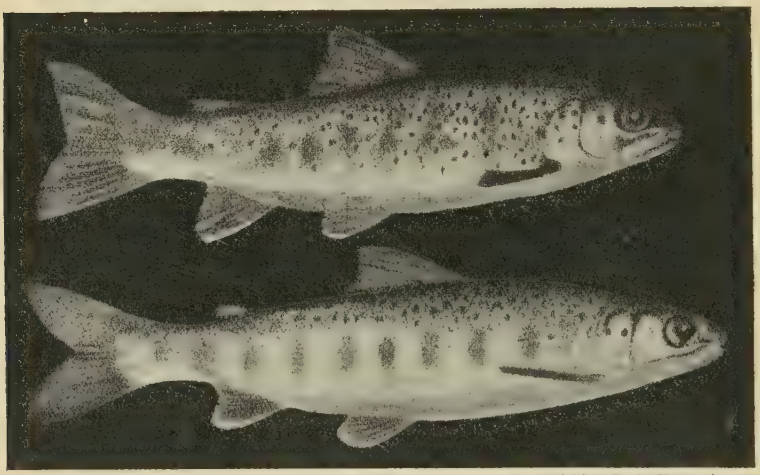
The internal organs as a whole are fairly similar to those of a lobster and perform similar functions (compare Figs. 73 and 75). Breathing is by means of gills, where cool red blood exchanges gases, oxygen and carbon dioxide, with the water flowing out by the gill slits. A fish's heart contains two communicating

chambers, one, the **ventricle,** expelling blood along the arteries to the gills, and the other the **auricle,** receiving the blood returning from the gills and other parts of the circulatory system. The heart is thus simpler than that of a reptile, which has one ventricle and two auricles, and still more primitive compared with the mammalian heart, which possesses two ventricles and two auricles.

The mouth communicates with the stomach by way of a long gullet or **oesophagus,** and a long intestine is looped in order to adapt itself to limited space. The **liver** performs the usual work of manufacturing a fluid which assists digestion in the intestine and also stored food substances obtained from the blood. The **kidneys** are linear, not rounded as in many other animals, but do similar work in removing waste products from the body. A special structure characteristic of most fish is the large **air bladder,** which adjusts the buoyancy of the animal but is not connected with respiration. The nervous system is more highly developed than that of a lobster and consists of a definite though small brain connected with various sensory nerves which enable the animal to perceive things (see, smell, hear, etc.), and motor nerves which control the movements of the muscles, etc. As in other animals, it is the muscular material that constitutes food for human consumption. The organs and muscles are supported by the skeleton consisting of a large number of separate bony sections or vertebrae connected together by cartilage. The rays or spines which support the fins are separate from the vertebral column.

Though the trout is much prized as an article of diet because of its flavour, the **salmon** is considered even more of a delicacy. This fish when fully grown is about three feet in length, though some may be longer than this and weigh as much as 80 lb. The salmon lives in the sea during winter, but ascends the rivers in spring in order to lay its eggs there, though some live permanently in lakes and rivers. The young salmon are known as **parr** and closely resemble trout in their surface markings, but when they are about two years old they become more silvery and are then termed **smolts.** The smolts go down to the sea in early summer and are then known as **grilse,** but after one or two winters in the sea they return to the rivers to breed, after which

the fish is called a **kelt.** A salmon may lay eggs once only, or three or four times, and the length of its life is usually less than ten years. During its visits to fresh water a salmon takes very little food, but when in the sea it is very voracious, devouring small fish of all kinds. The best British salmon fisheries are in the rivers of Scotland, particularly the Spey and others flowing to the North Sea, though the fish usually frequents rivers facing



(*After J. A. Hutton.*)

FIG. 76.—TROUT (above) AND SALMON PARR (below).

the west, as in the Shannon, the Cheshire Dee and the rivers of North Devon.

The migrations of the salmon seem insignificant when compared with the journeys undertaken by the **eel** during its extraordinary life history. The common serpent-like eel lives most of its lifetime in fresh water, rivers and ponds of Western Europe, but in late summer the older eels leave their places of residence, descend streams and rivers, cross land if necessary to reach these streams, and then, making their way into the Atlantic, they proceed far out to some deep part, believed to be somewhere near the Azores. Here they lay their eggs, which eventually yield tiny, thin, flat and glassy creatures very unlike eels, and known

as **Leptocephali** (Fig. 77). These proceed eastwards, taking two or three years over the journey, and slowly changing in shape; then as young eels or **elvers** they proceed upstream to countryside ponds, where they live the main portion of their lives as ordinary eels, returning again to the sea in order to lay their eggs, never to return. Eels breed only once, and always in the ocean.

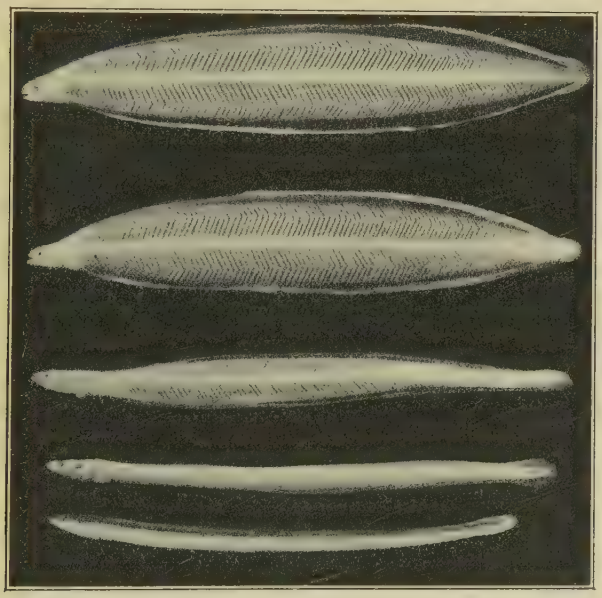


FIG. 77.—THE METAMORPHOSIS OF THE COMMON EEL.
(*After Dr. J. Schmidt, of Copenhagen.*)
(By courtesy of the Director, British Museum: Natural History.)

Though these are examples of *migratory fish* which spend part of their time in salt water and part in rivers, there are many families which inhabit only salt water, and others peculiar to fresh water. Among the latter are the British fish known as carp, barbel, chub, the little minnow, dace, roach, bream, and perch. The fierce, armoured pike is one of the few remaining examples of the Ganoid fishes, a group much more numerous far back in geological time. The sturgeon is a related marine type.

Among the typically marine types are the members of a very useful family called the *Clupeidae*, which includes herrings, sprats, and pilchards. Of these the first place of importance is easily taken by the **herring,** which inhabits deep water but comes near the shore periodically for breeding purposes. Immense numbers exist in the Atlantic, and their visits to the shores of Great Britain are constant, so that great quantities, more than 400,000 tons a year, are caught. Herrings are salted and packed in barrels. **Bloaters** are herrings which have been lightly salted and smoked, while in the case of **kippers** the fish have been split open before being ' cured.' **Sprats** are small fish of this family, and as in the case of herrings, they are salted and packed in barrels, but without having their digestive and other organs removed. Immature **pilchards** of the Atlantic and Mediterranean are beheaded, though the internal organs are retained, and are then salted and immersed in hot olive oil, the tinned product being the ' sardines ' of commerce.

The enormous quantities of fish consumed as food are nearly all derived from marine kinds, another family, the *Gaddidae* supplying us with large fish—cod, haddock, and hake. More than one million pounds worth of **cod** is landed at British ports every year. These fish frequent elevated portions of the sea floor as feeding grounds, so that the chief cod fisheries are those of the Dogger Bank in the North Sea, and of the submerged banks off Newfoundland and Iceland. **Hake** is quite common off the coasts of Devon and Cornwall. In spite of the enormous quantities of fish caught, the numbers available remain good on account of the extraordinary reproductive powers of these animals, a female cod's **roe** containing several millions of eggs. Few of these become adult fish, however, by reason of the destructive processes at work in the sea resulting from the struggle for existence.

Another interesting and useful group is that of the ' flat ' fish or side swimmers, among them being **sole, plaice,** and **turbot.** These spend most of their time lying on the sea floor. The under surface is white but the upper surface is coloured and contains the eyes, which are thus one above the other, as these fish swim on their sides.

Though food is the main commodity obtained from fisheries, there are some important by-products, notably **cod liver oil,** also **fish meal** and **fish manure** obtained from the heads, internal organs and otherwise waste parts generally. The chief fishing ports of Great Britain—Grimsby, Hull, Fleetwood, and Aberdeen —all have works producing these by-products. **Isinglass** is a substance obtained from the air bladder of the **sturgeon,** one of the few living representatives of an armoured type of fish referred to above. The chief sturgeon fisheries are in the Black Sea, and the isinglass imported from Russia is used for the manufacture of jelly and the refining of ale. The roe of the sturgeon supplies the delicacy known as **caviare.**

Whales are not fish, and the useful products obtained from certain species are considered later in a chapter dealing with mammals.

THE FROG

Life in a pond is perhaps not so varied as in the sea, but nevertheless there is a very mixed fauna ranging from microscopic protozoa at one end of the scale to amphibians—frogs and newts—at the other end. Larvae of many insects, water beetles, dragon flies and others, water bugs, the little jelly-like Hydra, the fresh-water mussel corresponding to the marine bivalves, pond snails, fish, and other creatures constitute a mixed crowd, many of which prey upon some of the others. The highest type of animal life found in this collection is the **common green frog** (*Rana temporaria*), classed as an *amphibian* because it can live both on land and in water. During the winter it hibernates, that is, it ' winters,' or remains inactive in the mud at the bottom of a pond.

The structure of a frog is in many ways much more advanced than that of a fish ; for example, the **skeleton** is much more developed, having definite limbs instead of fins (Fig. 78). In addition to the short central *spinal column* composed of nine *vertebrae*, there is a *shoulder girdle* consisting of shoulder blades or *scapulae* and other bones connected with those of the fore limbs. Similarly there is a corresponding *pelvic* girdle at the other end connected with the bones of the hind legs. There is a breast bone

or *sternum* in front, but there are no ribs to protect the internal organs.

If we examine the **limb bones** of a frog we find that they are composed of bones equivalent to those in the legs and arms of higher vertebrates. The front legs consist of the upper arm bone or *humerus* which articulates, that is, it is connected by a joint, with the radio-ulna, a compound bone consisting of the radius and ulna fused together. These are followed by several *carpel* or wrist bones which are in turn succeeded by the jointed bones of the four fingers and a rudimentary thumb. In the hind legs there is an arrangement of longer bones consisting of a femur or thigh bone, followed by another long bone, or rather two fused bones, the *tibia-fibula*, so called because it represents the separate tibia and fibula of the lower leg in most vertebrates. The *tarsal* or ankle bones are elongated, and there are five large toes and one small extra one called the *calcar* (spur), these toes during life being connected by a skinny membrane which forms an excellent swimming apparatus.

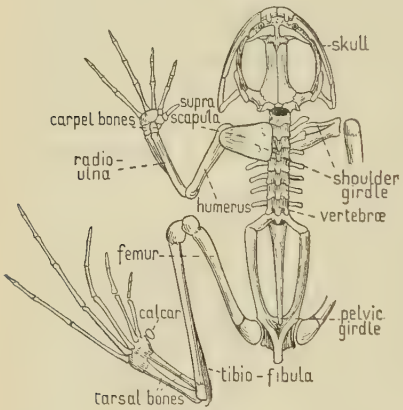


FIG. 78.—THE SKELETON OF A FROG.

The **skull** consists of a very large number of bones and is far too complicated to be considered in detail here, though one or two more apparent features should be noted. The two large spaces indicate the position of the eyes, and two smaller spaces farther to the front mark the position of the nasal openings. The lower jaw is very broad and has no teeth, though the upper jaw is furnished with many pointed teeth used for holding food but not for mastication. The frog has a long flexible and sticky tongue hinged at the front of the mouth, which is used for catching insects, etc.

The more important **internal organs** are here illustrated by a sketch (Fig. 79), in which the various parts are named in a manner similar to that used in the illustration of the internal arrangements of a fish, so that a comparison can be made without a detailed description. It must be noted, however, that **breathing** is performed by means of *lungs*, not by gills, in the adult frog. The **nervous system** is on a more advanced scale than that of a fish, but any adequate description is beyond the scope of this book.

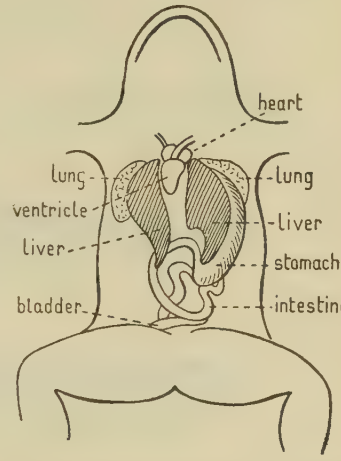


FIG. 79.—CHIEF INTERNAL ORGANS OF A FROG
SEEN FROM THE UNDER SIDE.

In its life history the frog undergoes some very interesting changes or metamorphoses (Fig. 80). In late spring the female lays hundreds of eggs in water and these swell into a slimy mass of rounded bodies collectively known as **spawn.** In the case of the toad, a related animal, the spawn is in the form of chains, not clusters. Each dark spot in the centre of a rounded gelatinous mass is an **embryo** from which a **tadpole** emerges in about fourteen days' time. At first these dark little creatures have no mouths and feed upon foodstuffs stored within the body. At this time they breathe by external gills and cling to objects by means of a pair of suckers on the under side of the head. In a few days' time a mouth is formed, so that they can feed upon vegetable matter, and internal gills form, while the external ones disappear. The hind legs now appear, and later the front ones develop at the same time as the lungs are being formed. For a time both gills and lungs can be used for breathing, but in the latter case the tadpole comes to the surface to inhale. Later, the skin is cast off and with it the gills are lost, so that the animal then breathes only by lungs; also its food changes from vegetable to animal

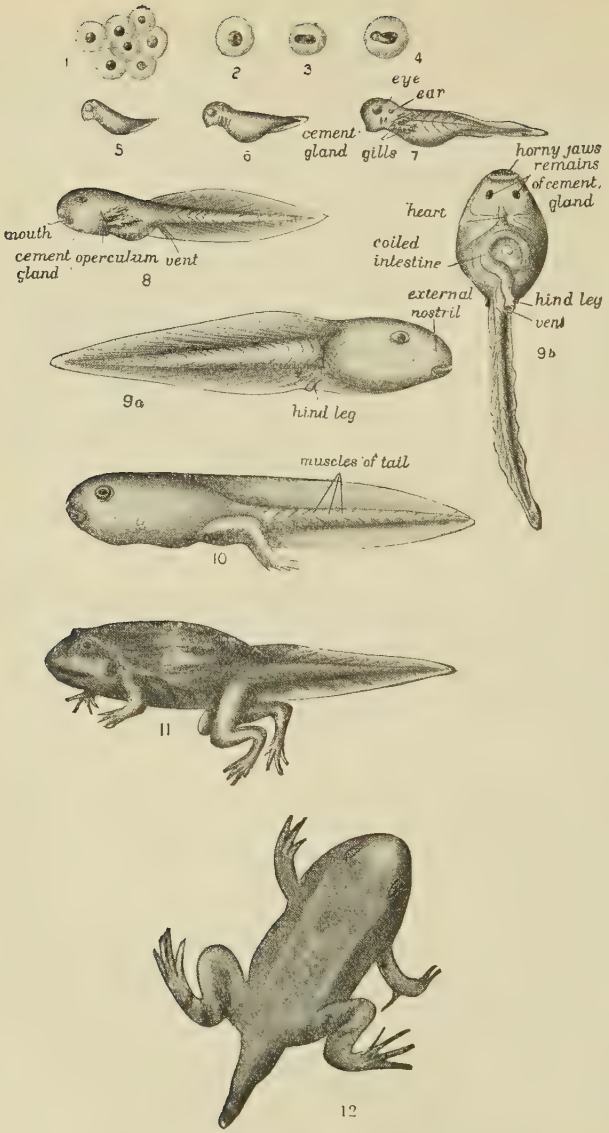


FIG. 80.—THE METAMORPHOSIS OF A FROG.

NUMBERS REFER TO SUCCESSIVE STAGES.

matter. In the final stages of development the hind legs become large and strong, the tail is absorbed, and the complete frog adapts itself to a life mainly on land generally about three months after the eggs are laid. The frog is a useful friend to a gardener, as it lives on slugs and insects.

The development of **toad tadpoles** proceeds along lines very similar to those of the frog, but in the case of **newts,** which are also amphibians, the eggs are laid singly, the tadpoles are pale coloured, the front legs appear earlier than the hind limbs, and the tail is retained in adult life.

CHAPTER IX

BIRD LIFE

The conquest of the air by birds and insects has given these groups of animals considerable advantages over less fortunate creatures which remain on the ground. The more obvious advantages of flight are escape from enemies, a wider field and greater facilities for food collection, and a quick journey to far distant warmer climates when food becomes scarce owing to the approach of winter in higher latitudes.

Fig. 81.—A Pterodactyl or Flying Reptile of the Mesozoic Period.

As we should expect from their well-developed or specialised structures, birds are a fairly late product of evolution and cannot boast such ancient lineage as that of insects. The oldest known fossilised bird remains have been found in a fine grained limestone, the Lithographic 'Slate' of Solenhofen in Bavaria, which is of Jurassic age (*i.e.* Middle Mesozoic). The remains of this primitive bird, called **Archaeopteryx,** show that it possessed feathers, but had teeth and other features inherited from the reptilian ancestral types from which birds are believed to be

descended. Flying reptiles, called **Pterodactyls,** existed a long time before the appearance of true birds, the remains of small species of pterodactyls being found in certain dark coloured limestones of earlier Jurassic age forming portions of the south coast of England at Lyme Regis, and inland in Dorsetshire, Somersetshire, and other districts (Fig. 81). In later rocks of chalk age, in America, remains of the huge flying reptile, the **Pteranodon,** show that these creatures developed an expansion of twenty feet from the tip of one wing to that of the other, but as in so many other cases, mere bulk proved a disadvantage, and the race became extinct.

ADAPTATION TO LIFE IN THE AIR

Flying animals, whether pterodactyls, birds, or bats, may be regarded as machines heavier than air, so that considerable force has to be exerted to raise and sustain them in the air. In this respect these animals are like aeroplanes. The force is obtained by muscular contraction, the muscles concerned being those of the arms, which in flying animals are very well developed and supported adequately by suitable bony framework. In the process of flight, the arm in conjunction with the air itself form an arrangement known as a lever (see also Ch. XIV). In any lever there are three components, the weight to be lifted, the power, and a fulcrum. When you catch hold of a horizontal bar above your head, and pull yourself up, your body is the weight, your muscles supply the power, and the bar is the fulcrum.

Similarly, there is the weight of the bird's body, the power of the arm muscle ; but what constitutes a fulcrum ? The air itself, particularly that portion of it *just under the outer edge and tip of the wing* is the fulcrum. So rapid are the wing beats, sometimes as many as 200 per minute, that the air offers considerable resistance, and the bird literally knocks the air and rebounds upwards as the result. In some early attempts at human flight artificial wings were attached to a man's arm, but such a method was doomed to certain failure since the human arm is not adaptable for such use, and the muscles are far too weak in proportion to a person's weight.

A bird is a master in the art of using air resistance, so that it soars upwards, glides horizontally, or swoops downwards just as it desires. The tail feathers constitute the main steering gear.

Now consider the general structure of the wing or arm in each of the three cases—pterodactyl, bird, and bat, the last named being a mammal (Figs. 81 and 82).

In each there is a humerus or upper arm bone, next the radius and ulna, forming the forearm, then the hand, the part which shows such variation in the three types. The pterodactyl had a skinny membranous wing supported by an enormously developed fifth finger and attached to the leg, and in some species to the tail as well. There were four other rudimentary fingers

FIG. 82.—THE ARM AND HAND OF A BAT COMPARED WITH THOSE OF A BIRD.

not concerned with flight. A bat also retains the primitive five-fingered hand, but four of the fingers are greatly enlarged and share the work of supporting a membranous wing which, like that of the pterodactyl, is also connected to the legs and the tail.

In a bird the hand is better adapted to the requirements of flight; it is highly *specialised*, consisting of one well-developed finger and parts of two others. The case is somewhat similar to the foot of a horse, which has one highly specialised toe and mere long splinters representing two other toes. The large finger of a bird corresponds to digit number two of any animal still having the primitive unspecialised hand with five digits. Perhaps the most remarkable feature of this adaptation to flight is the possession of feathers, which are so beautifully arranged as to form a perfectly air-tight sail when the wings are extended.

A typical feather has a central shaft or stem, on either side of which there is a web-like vane composed of very numerous thin

and flat structures called **barbs.** The barbs interlock with one another by means of minute hooks termed **barbules.** In flightless birds, such as the ostrich, where an air-tight arrangement is not required, the barbules are not developed properly, there is no interlocking, and the feathers are consequently of a more 'fluffy' or discontinuous character. Marabou feathers, used as articles of dress, are similarly degenerate types of feather known as semi-plumes. At the base of a feather there is a hollow shaft known as a quill.

In most birds, the larger feathers which cover the body and so determine its general outline, are known as **contour** feathers, and these connect with the body along definite tracks. Smaller feathers hidden beneath the larger ones are called **down** feathers; those obtained from certain birds, particularly water species, such as the swan and the eider duck, are of commercial value. In some birds, for example pigeons, the down feathers are completely absent.

The plumage of birds is periodically shed in the process known as moulting, which corresponds to the shedding of scales by reptiles. Many birds moult twice in a year, during spring when the smaller feathers only may be discarded, and again in autumn when a complete change of covering occurs, giving rise in some cases to distinct seasonal variation in appearance.

Some birds, such as swallows and martins, moult only once, while others, like the ptarmigan, moult three times in a year. Various species exhibit considerable variation in the period and frequency of moults during their first year when growth is required.

The bird's great superiority in powers of flight is an example of advantage gained by specialisation, and as we shall see, the wing is by no means the only part of a bird that has become specially adapted to certain functions. The digestive system is arranged to suit certain kinds of food, and the feet are so formed as to be particularly suitable to perching, climbing, wading, running, or swimming as the case may be. But for the present let us return to the study of the bony framework.

SKELETAL STRUCTURES

Many of the bones are porous or cellular, which combines strength with lightness, and often these cavities are in direct communication with the respiratory or breathing system so that such bones themselves are aerated (Fig. 83). In most birds the humerus or upper arm bone is pneumatic, and if this bone be broken it is possible by blowing down it to inflate the lungs of a dead bird if the windpipe is first tied up.

If we examine the skeleton of a common fowl (Fig. 84), we find that its component parts are somewhat similar to those of a frog, though in some ways it shows considerable advances in complexity and specialisation.

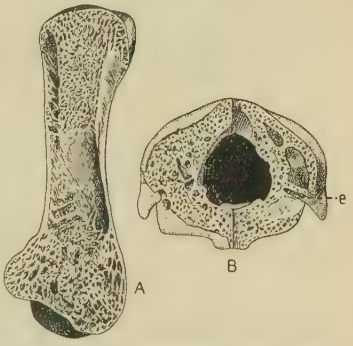


FIG. 83.—SECTIONS THROUGH (*A*) THE FEMUR OF AN OSTRICH, AND (*B*) THE SKULL OF A CARINATE BIRD.

In the fowl the vertebral column is much longer, having a large number of vertebrae in the neck and several in the tail, the furthest being fused into a bone called the **pygostyle** which forms an adequate support for the tail feathers.

The **sternum** or breastbone of a frog is relatively small, but that of a fowl is very large and has a prominent crest or **keel,** the whole forming an excellent support for the powerful muscles necessary for flight.

In ostriches or other flightless birds, the keel is much reduced or absent altogether; it is not required. The breastbone is also connected to five pairs of ribs which join with other ribs attached to the backbone, though there are a few *free* or false ribs connected to certain vertebrae but not to the sternum.

The ribs attached to the backbone bear oblique extensions, called **uncinate processes,** which form little cross bars from one rib to another, thus affording additional support.

The shoulder blades are long and narrow, while the collar

bones or clavicles unite to form the peculiar V-shaped bone popularly known as the 'merry-thought.' In the pelvic region the girdle bones are fused together to form an elongated compact mass. Forming the hind limb are a stout **femur,** followed by a compound bone, due to the fusion of the tibia and fibula, though separate knob-like terminations indicate the true character of

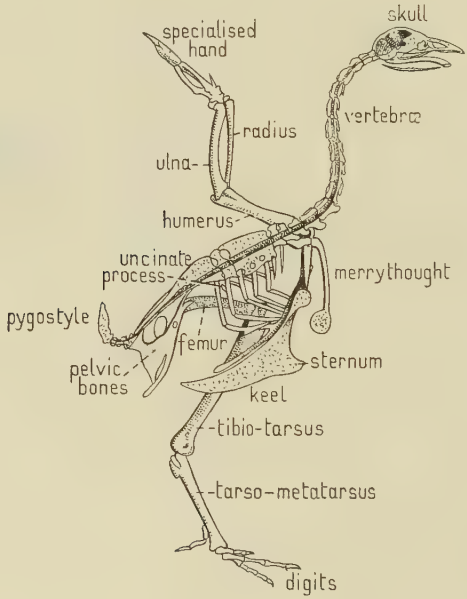


Fig. 84.—The Skeleton of a Fowl.

this bone, and a still lower compound bone, the **tarso-metatarsus,** often miscalled the ' leg.' This bone is really equivalent to the ankle bones of mammals, and is connected to four jointed toes, the first one being directed backwards, the others forwards. This arrangement of toes is that also found in the Passeres or perching birds, a group that includes most of the small birds seen in our gardens.

It may be as well to consider now the various other arrangements of feet adapted to different kinds of work (Fig. 85). In

most land birds the feathers extend right to the toes, though in the common fowl and others of its class (*Gallinacea*) scales cover the tarso-metatarsus. Climbing birds such as the cuckoo have rather long toes, two directed forwards, the other two backwards. Swimmers like the duck are furnished with web-like processes between the three front toes and extending as far as the very tips. Compare the very much smaller webbing between the

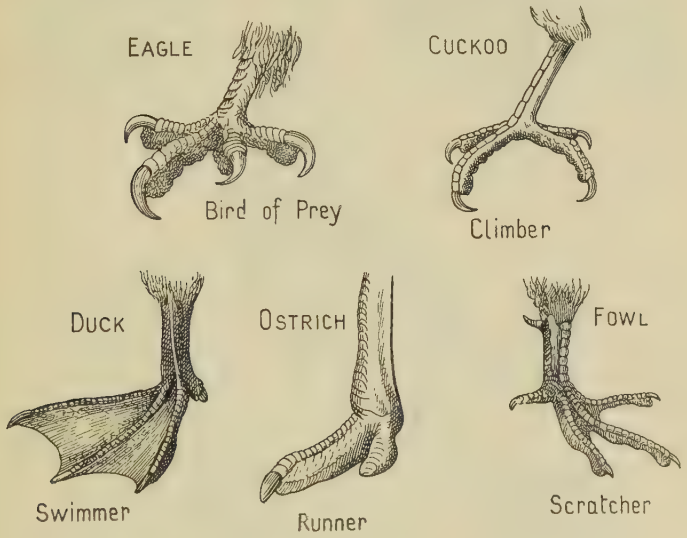


FIG. 85.—TYPES OF BIRDS' FEET
ADAPTED TO VARIOUS FUNCTIONS.

toes of a fowl. In cases such as the pelican where the feet are used for steering, the webbing embraces the fourth toe as well. Waders like the stork have long legs with toes having little or no webbing between them. The ostrich and its allies have powerful hind limbs having only two toes, an arrangement more convenient for running, and one toe, furnished with a nail, is much longer than the other (compare the one toe of the horse).

Birds of prey, illustrated by the eagle, are furnished with four large toes, each bearing a powerful claw.

We have now briefly considered specialisation of hands and feet, and the skull furnishes other examples, the beaks being adapted to the mode of feeding. A bird's skull is composed of a large number of bones, but those forming the cranium or brain

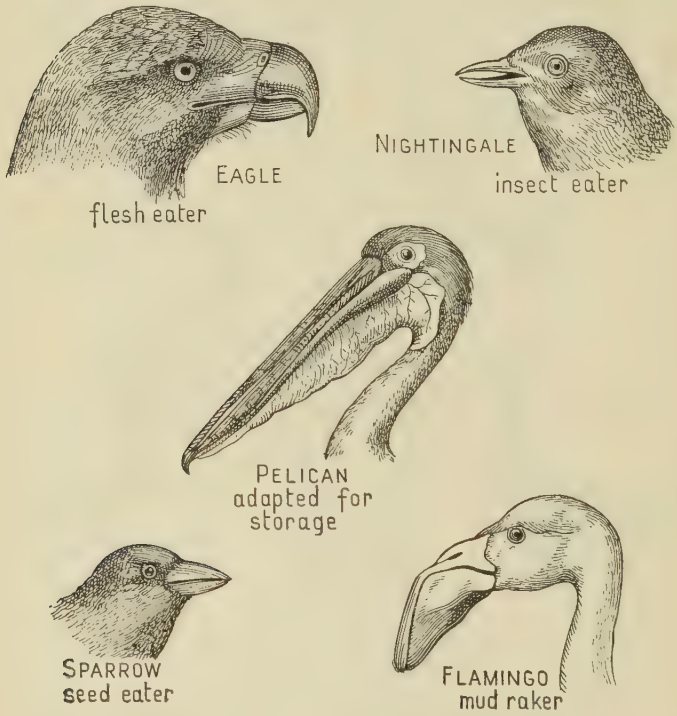


FIG. 86.—TYPES OF BIRDS' BEAKS
ADAPTED TO VARIOUS FORMS OF DIET.

case fuse together in adult life so that the lines of division or sutures seen in a mammalian skull are absent except in young birds. The junction of the head with the neck is made by means of rounded bones called **condyles,** and birds resemble reptiles in having only one condyle, whereas in mammals there are two.

The bones of the face are prolonged to form beaks which are covered by a horny substance, which in some cases has a rough saw-like edge, though nothing analogous to teeth is found in any modern bird. Eagles, vultures, and other birds of prey have strong hooked sharp beaks capable of tearing flesh (Fig. 86), though some birds, notably the parrot, use a curved beak, not for tearing food, but as an assistance in climbing. Insectivorous birds, such as the nightingale, possess rather long thin pointed beaks, while those of seed eaters, the common sparrow for example, are shorter and wider. Ducks and others which search for food in water have very wide beaks, while the peculiar bent mandible of a flamingo is adapted to searching for food in the mud. The pouch attached to the lower jaw of a pelican serves as a means of storage, the food being consumed when desired.

INTERNAL ORGANS

The digestive system of a bird is rather different from that of the frog or that of a mammal. **Saliva,** the juice which operates in the mouth of most animals, plays no part in the digestive process of a bird. There is a wide and long gullet or **oesophagus,** a lower portion of which is expanded considerably, forming a cavity known as the **crop** (Fig. 87). Here the food is retained for some time, softened, and then passed into a still lower cavity, called the **proventriculus,** which is really a second expansion of the gullet where glands prepare digestive juices and pour them upon the food. From the proventriculus the food is passed to the **gizzard,** the function of which is mechanical, the food being reduced to small particles. This is a strong muscular organ having a thick horny lining and capable of grinding up hard food such as nuts; small stones, etc., are deliberately swallowed to help in the process. Thus the proventriculus and the gizzard together do chemical and mechanical work analogous to that done by the stomach and teeth of most other animals. The food being thus prepared proceeds along the fairly long and tortuous **intestine** where most of it is absorbed. As in other animals we have considered, a large **liver** secretes a bile-like fluid and passes it into the intestine, and another glandular organ, the **pancreas,**

situated at the upper end of the intestine, supplies a fluid which, like bile, is concerned with the complex chemical processes of digestion.

Breathing is performed by very spongy lungs which communicate with certain air sacs placed near the top and sides of the body cavity, and as has been stated above, many cavities within the bones are also included in the air circulation. The windpipe of a bird is peculiar in consisting of a series of bony rings. The voice in mammals is produced by the **larynx**, but in birds it is produced in the **syrinx** at the lower end of the windpipe.

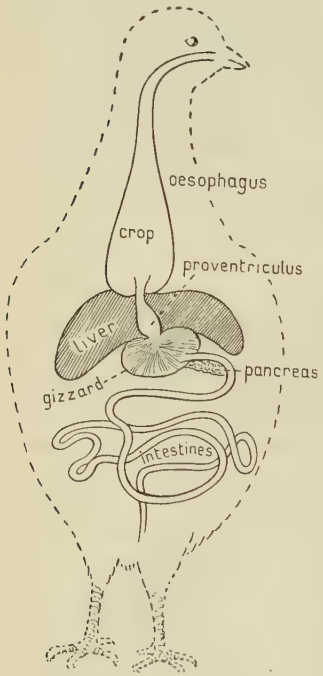


FIG. 87.—THE DIGESTIVE ORGANS OF A BIRD. (DIAGRAMMATIC.)

Both the circulatory and nervous system are very much more advanced in type than that of a reptile. As in mammals, the heart contains two ventricles and two auricles, which means that the impure or venous blood does not mix with the pure arterial blood (Chapter X). The blood temperature is considerably higher in birds than in any other animals, and may be as high as 112° F., as in the swallow. This high temperature, which accompanies a high degree of vitality, must be maintained, so that an inactive life due to hibernation is not possible; birds which cannot procure food in winter migrate to a warmer country.

The brain, though better developed than those of lower vertebrates, is smooth and rounded. Certain senses are particularly well developed, eyesight being better than in any other class of vertebrate animal. The eyes, which are large in proportion to the size of the body, are protected by movable eyelids and by a

transparent membrane. A special feature consists of a ring of bony, overlapping plates, forming an adaptable aperture in front of the eyeball so that focus can be adjusted to far distant objects, the range of vision being thereby greatly increased.

Hearing is acute, but there is no visible external ear, the opening to the internal ear, situated a little lower and behind the eye, being covered by feathers. The other senses of touch, taste, and smell are not so well developed, and differ considerably in different birds.

MIGRATION

The approach of winter in temperate latitudes means the failure of food supplies for enormous numbers of birds, hence vast hordes migrate to warmer climate where both animal and vegetable food materials still abound. Many centuries ago certain facts were known concerning migration, but owing to the difficulty of the problem, we are, even now, unable to understand the subject entirely. A few salient facts have been definitely established, however.

The fundamental reason for migration is lack of food, birds themselves being as a rule able to withstand mere fall in temperature since they are warm blooded and provided with a thoroughly efficient protective covering of feathers. Such birds as do not migrate are endowed with special ability for obtaining such food as may be obtained in winter. For example, grouse feed on the needle-like leaves of coniferous trees or burrow in the snow for their food. Birds which remain in a region throughout the year are known as **residents,** one of the most common British residents being the bird known as the hedge sparrow, though it does not belong to the sparrow family. Some of the pied wagtails afford another example. But the great majority of birds are migratory, and it may reasonably be asked why they do not remain all the year round within the tropics where it is never winter. The excessive heat of some lands may be nearly as injurious as considerable cold, since leaves become parched and insect life is scarce in less watered tropical regions.

In the more favoured tropical areas there are already enormous numbers of residents, and these would naturally be seriously affected by the settling of countless millions of birds now inhabiting temperate latitudes. These temperate types must pass from such latitudes, northern or southern as the case may be, to corresponding latitudes in the other half of the earth as

(*Photo: by Messrs. Wyles.*)

FIG. 88.—GULLS ON THE WING.

seasonal variation occurs. In general, most species which live in high latitudes north will in northern autumn migrate to fairly high latitudes south, and the greatest distance is traversed by such birds as the Arctic tern, which passes from the Arctic to the Antarctic circle, a distance of more than 9000 miles. Most British migrants winter in South Africa.

Local geographical conditions may modify the general rule;

for example, the climate of the British Isles being maritime or less extreme than that of mid-Europe, some species which are migratory there may remain as residents in Britain. Vast hosts of larks, thrushes, etc., which summer in Central Asia, move westwards in winter to the milder climate of Western Europe without much change of latitude. In high, mountainous regions a descent from great altitudes to lower levels brings about the necessary alteration in conditions, and a journey to the south is then not necessary. Again, snipes, redwings, woodcocks, etc., which spend summer within the Arctic Circle, are satisfied with winter conditions in the British Isles without proceeding any farther south. But these cases may be considered as variations of the general rule due to certain causes.

The general great trek southwards takes place *en masse*, millions making the journey together, and often flying at an altitude of 10,000 feet and at a rate of 120 miles per hour, though the speed is largely influenced by prevailing winds. Many birds become exhausted and fall to the earth, and it is these stragglers that tell the experienced ornithologist that vast hordes are on the wing, since the altitude of flight is often so great as to render the flying hosts invisible. The migration instinct is communal in character, and the journeys are made at certain times and along definite routes, though the return is not always by the same way as that of the outward voyage. Much of the journey may be taken at night, and sometimes, when the host is flying low, some favoured lighthouse keepers obtain a view of dense feathered legions attracted by the glare.

ECONOMIC ASPECTS OF BIRD LIFE

A simple statement of accounts estimating the amount of harm done by many birds as against the benefits obtained from various species is not easily made. It often happens that the same species is harmful in some ways and beneficial in others. Thus the thrush and the blackbird are destructive with regard to fruit but also destroy slugs, insects, and other garden pests. Some birds are almost wholly a nuisance, and among these must be placed the true sparrow, which destroys grain and damages the

shoots of young plants, though another type of bird called the hedge sparrow, the diet of which consists of insects and worms, does work of a beneficial character. Undoubted enemies of agriculture are the members of the crow family, particularly the raven, which is quite capable of killing small or weakly sheep, and the behaviour of crows and rooks is not much better.

When we consider the larger birds of prey, we again find that some are harmful, others are beneficial. Though some of these, the condor for example, eat carrion or dead bodies, they are not above sheep stealing. On the other hand, the South African secretary bird eats snakes, while the kestrels, buzzards, and owls feed upon rats, mice, and insects, thus performing a useful service.

Though the feathers of the ostrich, goose, and others are of value commercially, the more obvious beneficial part played by bird life in human affairs is as a source of food, and most, though not all, of this food material is supplied by the group known as **game birds,** which includes the domestic fowl. Most members of this group—pheasants, woodcock, grouse, partridge, ptarmigan, etc.—are too well known to need description, but it must be observed that though some, such as the partridge, are natives of Great Britain, many of them were originally introduced into Britain from other countries. The common pheasant came from Asia Minor, while both the ring-necked pheasant and the golden pheasant have been imported from China. The turkey is a native of North Mexico, and the ordinary fowl is considered to be descended from the wild jungle fowl of India. In order to insure against the extinction of the more prized game birds, pheasants, etc., special **game laws,** which make it illegal to destroy these birds during certain parts of the year (the breeding season) are enforced.

Enormous supplies of poultry and turkeys are obtained from birds cultivated on farms, etc., the Christmas demand for the latter being now so great that many birds are imported from France and elsewhere on the Continent. Other birds not in the same group are geese and ducks.

In addition to the flesh of the fowl, goose, and duck, their eggs are of great value as a food material.

An account of the development of the chick within the egg is quite beyond the scope of an elementary book, but the chief structures of a fowl's egg just after it has been laid should be observed (Fig. 89). The chief part or **embryo** from which the young fowl will develop is in the central yellow portion or **yolk,** which contains a **germinal vesicle** or nucleus. Surrounding the yolk is a thin **vitelline membrane** separating the yolk from the

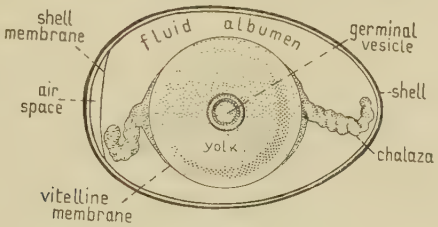


FIG. 89.—SECTION THROUGH AN EGG OF THE COMMON DOMESTIC FOWL.

outer albumen or **white of egg** in which it floats. As the yolk rolls over to keep the germinal vesicle near the top when the egg is moved by the sitting hen, it is protected by two whitish cords or **chalazae** which act as shock absorbers. Between the outer shell and the albumen is another thin membrane which contracts near the less pointed end of the egg, leaving an air space. The albuminous material is stored food matter for the young developing embryo, and in consequence the chick can, unlike some creatures, complete its development before it leaves the egg ; there is no need for any subsequent metamorphosis.

CHAPTER X

THE RABBIT AND OTHER MAMMALS

The animals which are of the greatest use to mankind belong to a very large and varied group called **mammals**, a name due to the fact that the young of animals in this group are fed by their mothers' milk. That docile and well-known creature, the cow, is a mammal, and cow's milk has become an almost universal article of food amongst civilised peoples. Goat's milk and that of one or two other mammals are also employed at times as a food for human consumption.

Enormous numbers of animals of different species belong to this great group—cattle, sheep, cats, dogs, rabbits, mice, horses, elephants, lions and others far too numerous to be mentioned, but all of them possess certain common characteristics that differentiate them from birds, amphibians, and other forms of animal life described briefly in previous chapters. All mammals with the exception of some of the types which have become adapted to life in water, possess four limbs ; all have a blood temperature higher than of fish and reptiles, but generally lower than that of birds ; and most are characterised by skins of a hairy nature.

The development of hair or fur is a mammalian mode of adaptation to climate, and to some extent corresponds to the development of feathers by birds ; and like the plumage of birds, fur often adapts its colour to the surroundings, this affording some protection to its wearer. Relatively a few mammals living in hot climates dispense with hair and have fairly smooth though very thick skins, for example, the elephant, rhinoceros, and hippopotamus. On the other hand, monkeys, kangaroos, tigers, and most others occupying hot lands, still retain hairy skins,

though it may be observed that the thickness of these furry coverings generally increases as the climate becomes colder, so that the regions where hunting for furs is carried on are chiefly those in high latitudes or near the polar regions—around the Hudson Bay in North America, for example.

Our knowledge of the early history of the mammalia is meagre owing to unfortunate gaps in the geological record, a matter which, however, may be improved by future discoveries. It is believed that the earliest known mammal remains consist of the tooth known as *Microlestes*, found in rocks of Triassic age, and supposed to have belonged to a creature related to the low order of mammals which includes the kangaroo of modern times. Much better specimens, consisting of complete jaws and teeth of somewhat similar small animals, have been obtained from certain fine grained rocks of Oolitic age, but specimens of more advanced mammals, which may be regarded as the early ancestral types of our cattle, etc., make their appearance in the relatively young tertiary rocks.

Strata of such age in various parts of the world—the Himalaya, North America, Patagonia, Egypt, etc.—have supplied much material in the shape of fossil bones and skulls, which has enabled experts to trace the family history of several important mammals, including the horse and the elephant.

Numerous valuable collections of later or pleistocene mammalian remains have also been obtained from various river gravels and caves, such as Kent's Cavern near Torquay, and in some cases the still more interesting flint implements of primitive man have been found associated with the remains of animals against which he had to contend.

The class Mammalia is so great that only a very brief résumé of certain facts concerning some types can be given in a book of this scope. The main sub-divisions or orders of the class are as follows, those mentioned first being the lowest or least highly organised types.

The Monotremes, including the ant-eater and the peculiar duck-billed platypus of Australia.

The Marsupials, or animals of the kangaroo kind.

Edentata, or toothless mammals of the sloth kind.

Sirenians—manatees and dugongs.
Cetaceans—whales, porpoises, and dolphins.
Ungulata, or hoofed animals, including cattle, sheep, deer, horses, etc.
Rodents, or gnawing animals, such as mice and rats.
Carnivora—flesh eaters, including lions, cats, dogs, bears, etc.
Insectivora—moles, shrews, hedgehogs, etc.
Chiroptera (*i.e.* hand winged), bats.
Primates—lemurs, monkeys, apes, and man.

In spite of this formidable array of orders, it is possible to select one example and study its organs and functions, which may serve broadly as a type for all the mammalia. For example, the mammalian heart is constructed on a similar plan whether it is the small one of a mouse or the large one in an elephant. Similarly, the apparatus of digestion is, on the whole, much the same in various members of the group, and exceptional cases, such as those of the ruminants, will be noted later.

THE RABBIT

The type usually studied by students of biology is the common rabbit, and one cannot do better than consider, without too much detail, the internal machinery of this creature in order to obtain an idea of the structure of mammals generally. Consider first a few elementary facts concerning the vital processes of digestion, circulation, and nervous control.

In the **digestive system** various parts corresponding to similar organs in a frog are easily recognisable, though the digestion and other functions in the mammalia are more complicated or highly organised than they are in amphibia, etc. Grass and other vegetable food is taken into the mouth, where it is mixed with the fluid digestive juice known as saliva secreted by glands within the mouth. Saliva plays an important part in digestion.

The food then descends the gullet or oesophagus and reaches the large curved stomach. The oesophagus passes through the diaphragm or muscular partition separating the digestive organs from the lungs and heart. Muscular contractions of the

stomach roll the food about, and gastric juices secreted by little glands are mixed with it, after which it is passed into the small intestine, a long, tortuous pipe named ' small ' because it is narrow compared with the wider larger intestine below. Near the top end of the small intestine, ducts permit the bile manufactured by the large, many-lobed liver, and stored in the gall bladder, to be mixed with the food, which is now like thick soup and known as **chyme.**

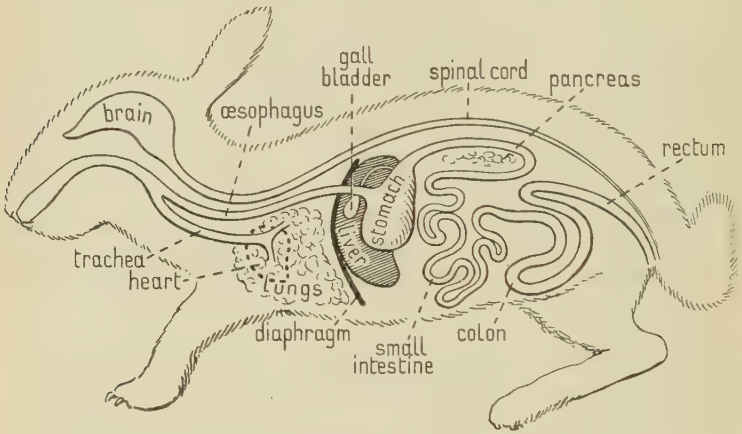


Fig. 90.—The Internal Organs of a Rabbit.
(Diagrammatic.)

The chemical changes which occur within the body are complex and varied; in fact the organs, particularly those of digestion, form a chemical laboratory of a very advanced character. Other fluids are added to the food material by the pancreas, a branching glandular organ. The large intestine is mainly composed of two portions, the colon and the rectum, the latter being connected with an exit for undigested material. Muscular contractions force the chyme along the intestines, and as it passes along, the available food-stuff is absorbed by means of great numbers of little projections called **villi** bearing blood vessels.

The intestines form a pipe system which, if straightened out, would be more than fifteen times as long as the rabbit's body.

A great length of intestine affords opportunity for the thorough absorption of available food-stuff.

The absorbed matter enriches the blood, which then takes nutriment to all parts of the body. The outstanding feature of the **mammalian circulatory system** is the four-chambered heart having two ventricles and two auricles, an arrangement which

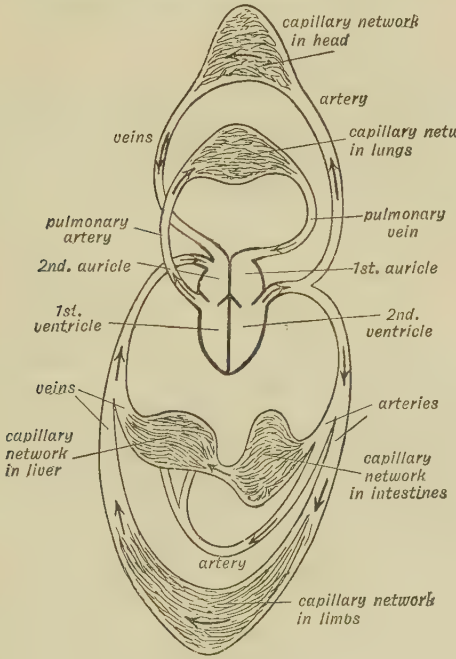


FIG. 91.—DIAGRAM REPRESENTING THE MAMMALIAN HEART AND CIRCULATORY SYSTEM.

means that the impure blood never mixes with the pure blood, as it does in many of the lower animals (Fig. 91).

The heart is a strong muscular organ roughly resembling a rounded and blunt cone, having the chambers called **ventricles** situated at the posterior or blunted end, and the two **auricles** placed anteriorly or in front. A ventricle communicates with a right auricle on the same side of the heart, by means of a

valve which ensures that the circulation of blood is kept in the right direction. Starting from the first ventricle, the blood is forced by muscular contraction along the pulmonary artery to the lungs. Here it is purified and returned through the pulmonary veins to the first auricle. The blood then passes into the second ventricle, from which it is forced along several arteries to all parts of the body other than the lungs. Finally, it returns by way of various veins to the second auricle and passes thence into the first ventricle again.

Certain important differences between arteries and veins must be noted. In arteries, the blood is being forced under pressure away from the heart, whereas in veins the blood is returning at much lower pressure to the heart. If an artery is cut, the blood spurts out like a fountain, worked by a regular but intermittent pump, but when a vein is severed the blood flows more slowly. Arteries branch repeatedly, eventually forming very minute vessels called **capillaries** which ramify through almost all parts of the body. Veins unite, forming a network of tubes conveying the blood back to the heart. The blood itself is composed of a fluid called the **plasma,** in which float many flat round coloured discs called **red corpuscles** and fewer white (colourless) bodies of indefinite shape known as **white corpuscles.**

The colouring matter of the red corpuscles is called **haemoglobin** and easily absorbs and gives up oxygen as required.

The lungs consist of a mass of air tubes divided repeatedly, until finally there are very small tubes each ending in a little sac or **alveolus.** Here oxygen from the air passes through the thin walls and enters the blood, while carbon dioxide goes in the other direction and comes out with the exhaled breath. The kidneys are two rounded glandular organs the duty of which is to remove water and **urea** from the blood.

The nervous system of a rabbit, as other animals, acts as a kind of sensitive telephone exchange controlling the movements of the various parts and the functions of various organs. The brain acts as a kind of central exchange, receiving messages or impressions by way of the **sensory nerves** and sending replies which work muscles, etc., by way of a different set called **motor nerves.** The brain of any mammal is a delicate and most com-

plicated organ, but in that of a rabbit, as in those of others, well-defined parts can be recognised—a front large portion called the **cerebrum,** and a back portion, known as the **cerebellum,** from which a long spinal cord extends down through the backbone or vertebral column. From the spinal cord various nerves branch and extend through the body.

SKELETAL STRUCTURES AND MODE OF LIFE

The skeleton of a rabbit in a broad general way resembles that of a frog, though there are some important differences, such as the much greater number of vertebrae (45), in the backbone or vertebral column, which ends in a tail (Fig. 92). The fore arm, which is smaller than the hind limb, consists of an upper arm bone or humerus followed by two bones, the radius and ulna, which

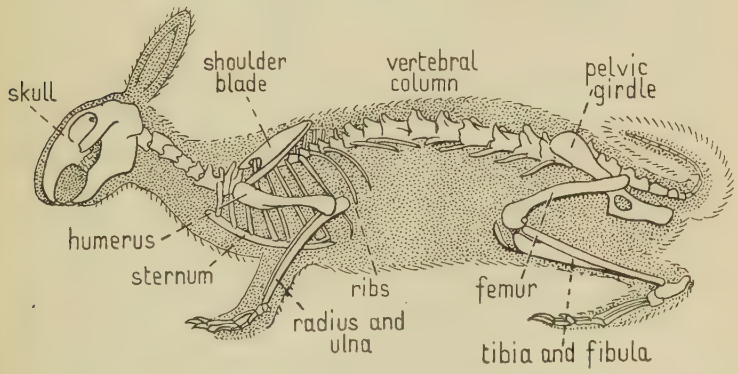


Fig. 92.—The Skeleton of a Rabbit.

together form the lower arm. These two bones are placed much nearer together than they are in a man and do not permit a rabbit to rotate its hand in the way a man can do. The rabbit's wrist is composed of numerous small bones, and then follow five digits or fingers, so that the hand (as in man) is said to be primitive or not specially developed, as that of a horse is for a particular purpose.

In the back limb of a rabbit it is easy to recognise the large

femur followed by the tibia and fibula forming the lower leg. Then come several small ankle bones connected to a foot consisting of four toes, since the great toe is absent. The foot is not quite so primitive as the hand. The size of limbs generally bears some relation to the amount of work performed by them, and in this respect the rabbit is no exception. Rabbits push themselves forward by means of their strong hind limbs; they leap rather than run, and the long outer legs reach the ground at positions beyond, or in front of, the fore legs each time the animal propels itself forwards. Other features of the skeleton that must be noted are the pectoral girdle in front, consisting of scapulae or shoulder blades, and the small clavicles, connecting with the sternum a breastbone which supports seven of the twelve pairs of ribs. All the ribs, of course, are joined to the backbone.

Near the hind limbs is the pelvic girdle, consisting of certain bones which become *ankylosed* or fused together in the adult rabbit.

Now consider quite briefly some modifications of the vertebrate skeleton to suit the needs of certain types living different kinds of lives. For example, compare the fore limbs of a rabbit with those of a bird and a bat described in the preceding chapter. The rabbit possesses the primitive five-fingered hand, and the limb as a whole is not highly specialised or specially adapted to a particular purpose. But in a bird's fore limb there is only one well-developed finger and fragments of two others in the hand. Such a limb is well adapted for the process of flight. So is that of a bat, but in a different way. Here the fingers themselves are greatly developed and support a leathery sort of wing, and though the primitive number five is retained, the fingers themselves are specialised and by no means primitive. If we consider the hind limbs, it may be observed that those of a rabbit are specialised to some extent, since they are large and particularly suitable for the mode of locomotion practised by the animal. But they are not nearly so specialised as are the feet of a horse. In this case each leg bears a foot having just one long well-developed toe, and merely splinters of bone representing two other toes on either side of the large specialised toe.

The foot of a horse has during countless generations of descent become particularly well adapted to speed in running. Members of the horse family were not always like this; fossil remains show that they commenced with five toes, then had four, later three, and now possess only one toe properly developed (Fig. 93). It may be more correct to say that one toe has become over developed at the expense of the others.

While considering the limbs of a horse it should be noted that the wrist (front limb) and ankle (hind limb) are very long, the

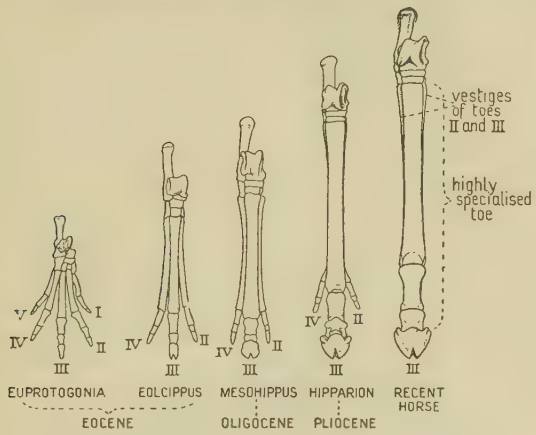


Fig. 93.—The Evolution of the Horse's Foot.

joint often mistaken for a knee really being the junction of the wrist with the lower end of the radius and ulna. The true knee is higher up nearer the body.

Perhaps the most interesting part of the bony framework of any mammal is the skull or hard covering which protects the brain, bears the organs of vision and hearing, and contains the teeth, the apparatus by means of which food is taken into the mouth and ground small enough for the process of digestion.

The skull, together with the lower jaw of an animal, affords evidence of its mode of life, and for this reason it also suggests many probable characteristics of the animal's bodily form. The teeth provide the chief clue concerning animal behaviour. The

rabbit's skull is elongated and is jointed or *articulates* with a lower jaw bone. Both the upper and lower jaws bear teeth, some incisors or chisel-like teeth in front, then a gap, followed by flatter pre-molars, and molars or grinding teeth behind. There are no sharp-pointed canine teeth as found in dogs, cats, and other flesh-eating animals. The **dentition** or set of teeth of a rabbit shows that the little creature is a vegetarian, feeding on grass, small roots, etc., and it is described as **herbivorous**. Because of its gnawing habits, it is called a rodent, and such creatures as mice, rats, and others having roughly similar dentition and living on the same type of food, are also classed as rodents. Though inoffensive in the sense that it does not prey upon other animals, the rabbit is destructive to roots, etc., and the rate at which it breeds has caused it to become a great pest in certain countries, particularly Australia,

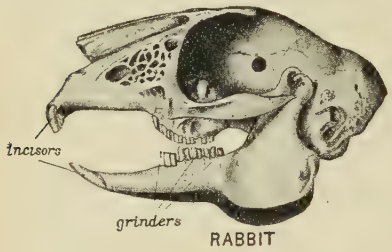


Fig. 94.—A Rabbit's Skull.

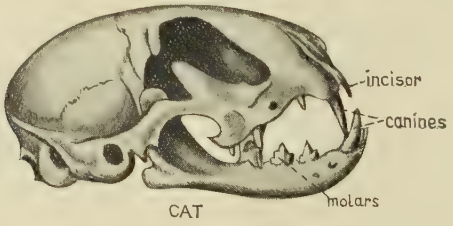


Fig. 95.—A Cat's Skull.

where a few rabbits, originally introduced as novelties or pets, produced many millions in a few years.

Now compare the skull and dentition of a rabbit with that of a cat or dog (Figs. 94 and 95). In the case of either of these flesh-eaters the teeth are relatively few, but all of them are sharp and pointed, some, the canines, being more pointed than the others. But even the back teeth or molars are somewhat

pointed and bear sharp edges. The teeth are all adapted to the purpose of cutting and tearing the flesh of other animals, and a creature living on such a diet is said to be **carnivorous** (*i.e.* flesh-eating).

Though a pet dog or cat may now appear inoffensive enough, it is descended from wild ancestors which lived a very active, predaceous life, that is, a life occupied by searching for prey. The teeth and jaws of a carnivorous animal are highly specialised, so are those of an elephant, but these are large and almost flat, being used as grinding mills for roots and branches of trees. An elephant is herbivorous.

Members of the carnivora—lions, tigers (cat family), bears, wolves, and foxes (dog family), and others—are all agile, their limbs and general structure being adapted properly to the type of life they have to live. As a rule, even their feet are padded, so that they may creep about silently, and in many cases the claws are withdrawn into sheaths when not required for active service. While this class of animal has many obviously offensive characteristics, it is the class that yields us nearly all the **furs** used as articles of clothing, rugs, etc. The skins of lions, tigers, and bears are used mainly as rugs, but different species of wolf, fox, skunk, and otter, and the smaller animals, ermine, sable, and martin, supply most of the materials used by the furriers and clothiers in the manufacture of fur coats, stoles, necklets, etc. The colour of the fur of many animals changes during the year to suit climatic variations in surroundings, and it is the white winter coat of the ermine that is so highly valued.

Seal skin, obtained chiefly from sea lions, sea bears, and to a lesser extent from true seals, is of considerable value, and these large marine animals also belong to the carnivora though they are not so active bodily as the others.

Seal hunting for the skins is carried on in the ice-floe regions of the North Atlantic, and a species of seal is also found in the Caspian Sea. Sea bears or sea lions, which are not true seals though closely related to them, yield the best furs, and are hunted in the South Atlantic off Patagonia and the Falkland Islands, but they are not found in the North Atlantic. Many

animals of this kind are plentiful in the North Pacific however. Much of the cheaper fur of commerce is really rabbit skin 'doctored' to look like something else. Some other rodents, particularly the squirrel, yield more valuable fur, while the coat of the little insect-eating mole is highly prized.

SEA-FARING MAMMALS

The largest surviving land mammal is the elephant, now found only in Africa and India, though formerly its ancestors roamed all over the northern hemisphere: remains of the mammoth are found in Siberia, N. Europe, and N. America. The elephant is an ungulate or hoofed animal though it has the primitive five toes, the skull and dentition being the specialised portion of its anatomy. Many of the bones of the skull are cellular or contain hollow spaces, so that they are light yet strong enough to support the massive tusks. Elephant tusks, which are greatly enlarged incisor teeth, are much prized as ivory, that from other animals, such as the walrus, being of inferior quality. Apart from their ivory, elephants are employed for hauling timber, etc., but largely on account of man's interference they are rapidly diminishing in numbers.

Now at first sight there appears to be little connection between elephants and whales, but if we look into the subject of the ancestry of these types we find a good deal of evidence to suggest that whales and other sea-going mammals may be descended from elephant-like creatures that took to a lazy life floating in the rivers, their bulky bodies being supported by the water. Weeds and other plants along the river-side could be used as food. It is a rule of nature that limbs or organs that are not properly used shall eventually dwindle away, or at any rate become less and less pronounced in successive generations; and this is exactly what is found by examination of the fossil evidence. Remains of animals have been obtained which show the limbs of elephant-like creatures in various stages of diminution. At the Natural History Museum, South Kensington, are specimens of such connecting links called *Zeuglodon* obtained from Eocene rocks in America and Egypt. A greater amount of fossil

evidence is available in the case of the sea cows or Sirenians, a connecting link with land animals being the *Halitherium*, the remains of which are found in tertiary rocks at Darmstadt in Germany (Fig. 96).

In these, the hind limbs have almost disappeared, while the fore limbs are represented by the humerus together with the radius and ulna, but there is no hand. It is generally believed that the Cetacea or whale family have originated in a similar manner from another group of marine animals.

Though whales have smooth skins and bodies outwardly resembling those of fish, they are true mammals, being warm blooded, breathing by lungs, and giving milk to their young.

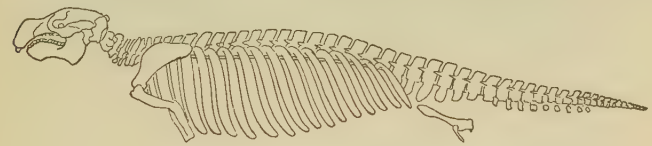


FIG. 96.—SKELETON OF *Halitherium schinzi*.
(By courtesy of the Director, British Museum: Natural History.)

There are several species of whale, some of more commercial value than others. Two of greater importance are the **Greenland** or **Arctic right whale**, found in northern seas as the name suggests, and the **Sperm whale**, inhabiting warmer seas within or near the tropics (Fig. 97).

The Greenland whale and a similar related form of the Antarctic region usually attain a length of about 50 feet and weigh about 220 tons. As in most animals of this group, the head is very large and extends about one-third of the entire length of the body. The nostril is placed at the top of the head, and during exhalation quantities of water vapour in the breath give the impression that the animal is spouting sea-water. One of the chief features of this species is the intricate arrangement of long, thin flexible plates of **baleen** or whale bone found within the mouth. There are hundreds of these plates forming a kind of sieve, preventing large objects from being swallowed. This whale has a relatively small stomach and feeds upon small molluscs, etc., caught by the simple process of keeping the

mouth open as the monster moves through the water. The food being of this nature, there are no teeth in the jaws of the Greenland whale. The whale bone (not really bone, of course), together with the fatty, oil-producing substance termed **blubber** found on the back and sides, are the materials for which the animals are hunted.

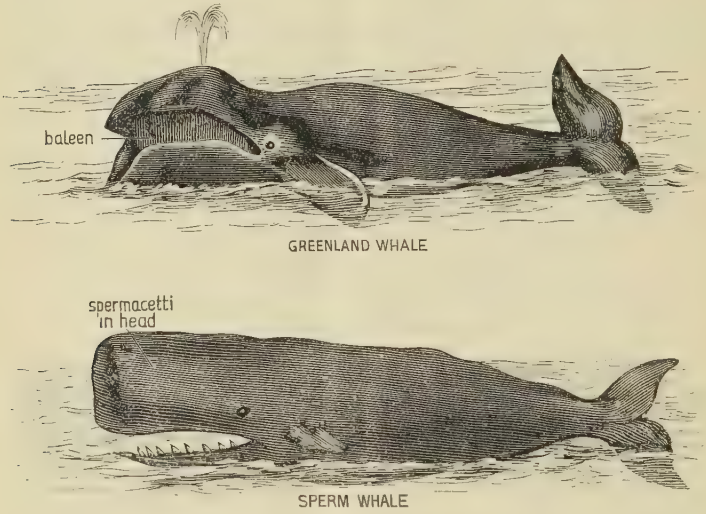


FIG. 97.—TWO OF THE MORE IMPORTANT SPECIES OF WHALE.

The Sperm whale or *cachalot* differs from the Greenland species in the absence of the complicated baleen structures. Its food consists of larger material, including cuttle-fish and other molluscs, and ordinary fish. The shape of the head is also different on account of the large mass of fatty matter above the front portion of the skull. A nasal opening or blow-hole is situated near the front of the head. A large number of conical teeth on each side of the lower jaw make this animal a much more formidable creature to hunt than the Arctic variety.

Oil, obtained from the layer of fat surrounding the body, and **spermacetti** wax, obtained by refining the oily matter of the head, are the chief commercial products. The whales as a class are

gregarious, that is, they go about in herds or ' schools ' sometimes containing thousands together. They have their enemies, however, the **Grampus,** or killer whale, a fierce member of the group attacking and devouring the others, even the larger Greenland and Sperm varieties.

The size of Cetaceans varies greatly, ranging from the huge **rorqual** attaining 85 feet, down to the **dolphin,** which is generally less than four feet in length. Several species of whale inhabit the British seas, the variety most often seen being the common **porpoise,** attaining an average length of 5 feet, the presence of which is undesirable since it feeds on useful small fish, such as herrings and pilchards. A certain amount of oil can be obtained from it, but the animal is not of much use commercially. So-called porpoise leather is obtained mostly from a larger animal about 12 feet long, called the **White whale,** and found in large numbers in Arctic waters. Only rarely is this kind of whale seen so far south as Scotland.

USEFUL HOOFED MAMMALS

Food, leather, wool, and certain products such as glue and bone ash, are the indispensable commodities we owe to the hoofed animals or ungulates. The group includes a great number of species : mountain goats, deer, camels, rare members of the horse family, hippopotamus, etc., which many of us may never see except perhaps in zoological gardens or a museum ; but, on the other hand, everyone is familiar with cows, sheep, horses, and pigs, types which constitute the chief sources of our animal products. All these animals have hoofed feet, those of the horse having simply one hoof at the end of a single toe, but most of the others having two hoofs (which look like one split in two) at the extremities of two of the toes. As mentioned above, the elephant has five hoofs on each foot, and a rhinoceros has three. The domestic pig differs from most of the other members of the group in possessing a full set of teeth containing all types—incisors, canines, pre-molars, and molars—indicating that nature intended it to eat a mixed diet. The pig is **omnivorous.**

On the other hand, cattle, sheep, and horses possess teeth that are not quite so numerous and are particularly adapted to chewing vegetable matter. The digestive processes of cattle, sheep, deer, and some other ungulates (but not horses) are peculiar, and these animals are known as **ruminants.** A cow's stomach, or that of another ruminant, consists of four parts, or, as it is sometimes described, a cow has four stomachs (Fig. 98). The food, commonly grass, is taken into the mouth and passed to the largest compartment of the stomach. After a while it is passed forward to the second chamber, where it is rolled up and sent back to the mouth to be thoroughly chewed. This secondary chewing is the ruminating process which is performed at leisure after the animal has taken in a sufficient store of material.

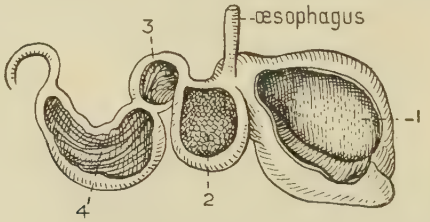


FIG. 98.—THE STOMACH OF A RUMINANT.
COMPARTMENTS NUMBERED IN ORDER.

The food is then sent back to the third part of the stomach, where it receives attention from digestive juices, and eventually reaches the fourth partition, where it is finally prepared for digestion in the intestine. There is no need to discuss here the obvious importance of the different varieties of food obtained from these ungulates.

The horns of cattle are hollow and permanent, whereas those of deer are shed periodically. Both horns and hoofs are made into various useful substances, such as combs, imitation tortoise-shell, knife handles, glue, etc. Leather consists of the skins freed from hair and treated to some special process, either **tanning** or **tawing,** in order to render the material proof against natural putrefaction or decay which would otherwise occur, since animal skin like flesh is subject to decomposition, unless preserved in

some way. In the process of tanning, so called because the skins are placed in solutions containing **tannic acid** obtained from certain vegetable substances, such as oak bark and chestnut, the hides are first cleaned to remove blood stains, etc. ; they are then softened by treatment with lime, so that the hair and outer skin or epidermis can be scraped off. This preliminary process, in which bacteria play a part, is known as depilation and lasts from 8 to 12 days according to the type of skin, softer material requiring a longer time. The hair, etc., having been removed mainly by machinery, the skins are then immersed for some time in the tanning solutions. Later they are treated to a **currying** process, which consists of adding oil and grease, and the article called leather is the final product. In the other process of tawing, the skins are submitted to the action of mineral salts, such as alum and salt, together with flour and white of egg. A special and rapid process, known as chrome tanning, consists of immersing the skins in a solution of sodium dichromate.

The stronger leathers are made from the hides of cattle exposed to all sorts of weather, and among the favourite breeds are those known as **shorthorn** and **Hereford.** The skins of sheep, goats, and calves yield lighter and softer leather, employed for the upper parts of boots, gloves, and light articles. Though nearly all leather is obtained from these mammals, other kinds are produced from the skins of lizard, crocodile, etc., and are used for fancy goods and even for ladies' shoes.

The world's supplies of wool for clothing are obtained from sheep and the closely related animal the goat. There are several species of wild sheep inhabiting the mountain regions of Asia, Mediterranean Europe, the Rockies of North America, etc., but wool is obtained from domesticated varieties. Of these domesticated types two classes may be recognised—those with horns, such as the **Dorset** and **Norfolk** sheep, and the **merino,** originally introduced from Spain, and those without horns, including such varieties as **Cotteswold** and **South Down** sheep. The merino is specially famous for its fine quality wool and the South Down is bred mainly for the excellent meat it makes.

Fine silky wool is obtained from certain goats, particularly the **alpaca,** which with the llama inhabits the mountains of Peru, and

attempts, more or less successful, have been made to introduce the alpaca into Australia and elsewhere.

The **Cashmere** goat of India and the **Angora** goat of Asia Minor are two other kinds noted for the quality of their wool. It will be observed that the fabrics sold as cashmere, alpaca, and merino are named from the animals supplying the raw material.

CHAPTER XI

THE HUMAN BODY AND ITS EFFICIENCY

The bony skeleton supporting the human body is constructed on a plan very similar to that of the skeleton of a typical mammal such as a rabbit or a cat (Fig. 99). Thus the fore limbs of a cat and the arm of a man contain similar bones — humerus, radius, ulna, wrist bones, and digits, though the shape and proportions differ in the two cases. In both cases these limbs are supported by bones forming a shoulder girdle, and similarly the leg bones are connected to others forming a pelvic girdle. In man, as in other mammals, ribs connected to the back bone (and some of them to the breast bone) serve to protect certain internal organs, including the heart and lungs.

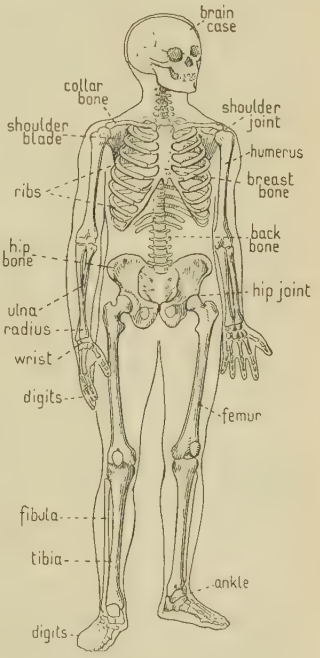


Fig. 99.—The Human Skeleton.

The similarity between the human skeleton and that of another mammal is, of course, most marked when a comparison is made with that of an anthropoid or man-like ape, such as a gibbon or chimpanzee. The general plan of one is much like that of the other, but the chief differences which account for

man's structural superiority include the straight femur or thigh bone, and the erect poise of the head upon a gently curving backbone.

These features enabled man to walk in an erect position, so that his hands could be used for grasping and manipulating external objects. By this means much knowledge of his surroundings was gained, and in a great many ways man's correspondence with the objects around him was more thorough and intimate than that of animals not erect and not so free to use their hands. An increase in brain power and intelligence was bound to result from the possession of these structural advantages, and it is in the formation of the skull and lower jaw that man differs most from the apes. A comparison of the skull of a chimpanzee with that of a man (average European) shows that in the latter the brain case is much larger, with a pronounced forehead rising at a high angle from the scarcely noticeable ridges above the eyes. In the adult ape, the brain case is small, the forehead is low, slopes backwards at a relatively low angle, and there are pronounced ridges above the eyes. In man the lower jaw or mandible is not so prognathous, that is, it does not protrude so far in front of the face as it does in the chimpanzee. This remark applies to the jaw as a whole, and it should be observed that a pronounced chin is a definite human characteristic.

The teeth of man, particularly the canines, are not so offensive or pugnacious in character as those of an ape, since greater intelligence substituted cunning for physical violence, human teeth being used mainly for eating purposes and not as fighting weapons. This, of course, applies more to modern man than to some of the earlier types represented by fossilised remains of great antiquity.

REMAINS OF PREHISTORIC MEN

One of the most fascinating and important studies in natural history seeks to find an answer to the question—What is the origin of the human race? We naturally look to the fossil evidence to supply a solution to this problem, but unfortunately

the amount of such evidence is relatively small, since the discovery of human remains is accidental and of rare occurrence. The superior cunning of primitive man generally enabled him to avoid dangerous situations in which his body might be buried and so preserved, and skeletons to be fossilised must have been buried, since even bones gradually decompose and pass away as dust if left exposed to air.

Cunning did not always avail, however, and very occasionally human remains—bones, portions of skulls, teeth, and so on—are dug from old river gravels, cave earth, or other rocks which are geologically young, though of great antiquity when measured by ordinary historical units of time. The length of time separating us from the Pharaohs of ancient Egypt is extremely small compared with the hundreds of thousands of years which have elapsed since these fossilised human remains were entombed in their resting places. In some cases flint implements—scrapers, spear-heads, etc.—and teeth or bones of animals are associated with human remains, and these objects help to solve the question of the relative age of the rocks in which such remains have been discovered.

The most ancient and primitive man-like remains, which appear to be more ape-like than human, were discovered in **Java** by Professor Dubois some years ago. These objects, discovered in an old river gravel probably of late Pliocene age, included portions of a skull, some teeth, and a thigh bone or femur. The specimen has been called *Pithecanthropus erectus*, a name meaning the erect man-ape, and it is generally considered that the animal may be a link connecting the gibbons with man.

In the year 1912 the late Mr. Charles Dawson found portions of a skull and lower jaw in an ancient river gravel at **Piltdown** in Sussex (Fig. 100). Animal remains, teeth of certain early elephants, and both flint and bone implements found in the same gravel suggest that the deposit is of early Pleistocene age, that is, considerably younger than Pliocene rocks, but still very ancient. The glacial periods, during which ice covered northern Europe and palaeolithic man inhabited Southern England, were also of Pleistocene age, but the specimen found at Piltdown represents a much earlier stage in human development than that to which

the glacial man belonged. The Piltdown man has been named *Eoanthropus dawsoni* (the dawn-man of Dawson), and is certainly the oldest and most primitive type of undoubted human remains yet found.

The Piltdown specimen includes most of the bones forming the brain case, and though those of the face are absent, there is

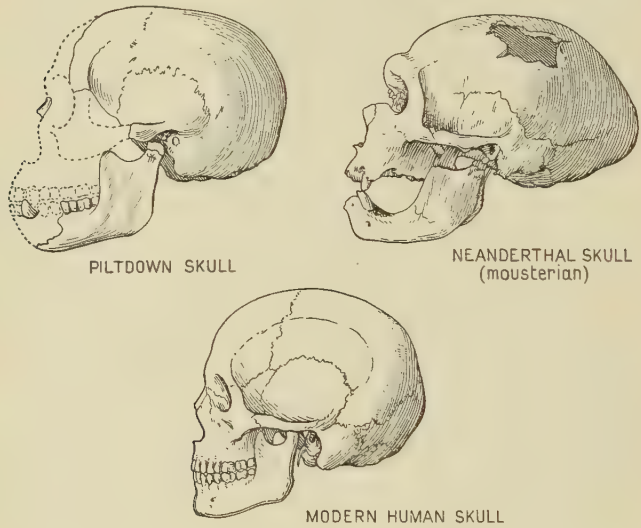


FIG. 100.—TYPES OF HUMAN SKULL.
(By courtesy of the Director, British Museum: Natural History.)

sufficient of the skull to show that it was essentially human in character.

A plaster cast of the brain case shows that in size the brain exceeded that of a native Australian, but was considerably less than that of an average modern European. The cast also shows that the *convolutions* or coiled appearance of the brain surface were not so complicated as in modern man, and it is this feature, the complexity of the convolutions, that appears intimately associated with degree of intelligence. Size alone is not very significant. For example, it has been estimated that the brain of the distinguished German statesman Bismarck was at least 600 grams

heavier than that of the famous mathematician Leibniz, who may have been the intellectual superior of Bismarck. The lower jaw of the Piltdown man is decidedly ape-like in character, so that the specimen really represents a race of beings related to both apes and man.

A lower jaw of decidedly human but primitive character was found near **Heidelberg** in Germany in 1907. It, also, was discovered in a river gravel, together with remains of elephant, bear, and other Pleistocene animals, and it is believed that Heidelberg man lived nearly as long ago as the man of Piltdown.

Remains of men of somewhat later times known as the **Mousterian** period are fortunately more plentiful, at any rate more of them have been unearthed. Though the name Mousterian is derived from Le Moustier in France, where remains have been found in a cavern, the most famous of Mousterian specimens is known as the **Neanderthal man,** since it was found in a cavern in the Neanderthal, near Dusseldorf in Germany. This discovery was made so long ago as 1857, and since then many other remains of similar primitive men have been discovered in various parts of Europe, particularly at **Spy,** near Namur in Belgium, and at **La-Chapelle-aux-Saints** in south-west France. It is interesting to note that all of these Mousterian specimens were obtained from caves. From the collective evidence we are able to state that Neanderthal man was generally of short stature, not so erect as modern man, and possessed a skull characterised by a fairly low receding forehead and prominent ridges above the eyes.

Human remains found in caverns and gravels of later Pleistocene age show that the later man of the old stone age (Palaeolithic) approximated closely in structure to modern man. Specimens of these later types are none too numerous, and it is to be hoped that future discoveries will add considerably to our knowledge of the subject.

THE MECHANISM OF MOTION

Microscopic examination shows that bones of the skeleton, as all other parts of the body, are composed of cells, but in this case the cells are impregnated with hard substances—phosphate and

carbonate of lime—and they are softer in early childhood than in adult life. Where bones meet there is a joint, which may be simply an immovable junction as in the bones of the skull, or may be a movable joint as that of the knee or elbow. So far as motion is concerned, movable joints are a necessity, and are usually formed by a terminal knob-like part of one bone fitting into a cup-like hollow in another bone. For example, the top of the femur or thigh bone fits into a rounded cavity called the *acetabulum* (vinegar pot) in one of the large bones of the pelvic girdle. In other cases a joint, such as that at the elbow, resembles the hinge of a door.

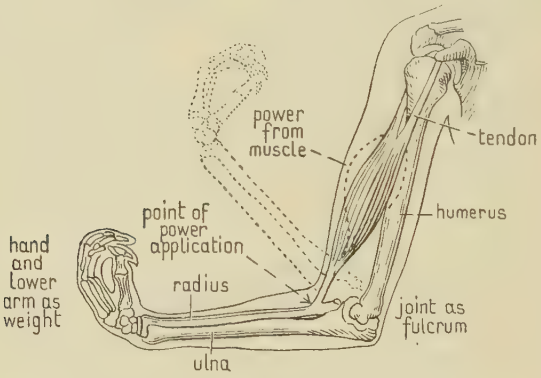


Fig. 101.—The Human Arm as a Lever.

Attached to the bones, usually by tendons, are **muscles**, which consist of bundles of fleshy fibres, capable of contraction or shortening when required. By such contraction the bones, and therefore the limbs and other parts of the body, are moved, thus enabling us to do various things. A well-known movement of the arm may be taken as a typical example. When the forearm is raised towards the upper arm, it is operated by a large muscle called the *biceps*, the upper end of which is connected to bones by two tendons, one to the shoulder blade, the other to the humerus (Fig. 101). The lower end of this muscle is connected to the radius of the forearm, and upon the contraction of the muscle the forearm is raised. Upon relaxation of this muscle and the

contraction of another on the outer side of the arm, the forearm is lowered again. It will be observed that the muscle and bones together form a lever with the elbow joint acting as a fulcrum (see Chapter XIV).

The movements of the leg are brought about in a very similar manner, muscles and bones together acting as levers of various classes according to the movement. Other muscular contractions cause the motion of the head, the neck, the hand, and so on.

Except in the case of certain nervous disorders, all of these movements are voluntary or controlled by the will, hence the corresponding muscles producing such movements are known as **voluntary muscles.** But there are others which perform their work without any conscious effort of the will and therefore called **involuntary muscles.** The chief examples of these are the heart, the muscles of the stomach, and those of the intestines which force the food matter along the alimentary or digestive tract. The movements of these involuntary muscles are rhythmic, and we are not conscious of their action.

Now, muscles whether voluntary or involuntary are controlled by **nerves.** The various movements and forms of physical work that we perform constitute our round of daily activities. Life consists very largely of muscular action, and the involuntary muscles perform functions that enable the voluntary muscles to do what we wish them to do. Without the control of the nerves, the muscles would be like a collection of independent pieces of mechanism and the body would be like a battleship that had lost its control station.

THE CONTROL STATION OF THE HUMAN BODY

The complete nervous system may be considered to consist of two portions—the **cerebro-spinal system,** which includes the brain and the spinal cord with their connected nerves, and the **sympathetic system,** composed of nerves and larger masses of nervous substance called ganglia. A disorder such as blushing is due to a disturbance of the sympathetic system. These nerves and ganglia extend along the front and sides of the vertebral column, and nerves proceeding from them control the movements

of the involuntary muscles concerned with the action of the heart, intestines, and so on, as well as all muscular movements.

Of the cerebro-spinal system the largest portion is the brain, which is protected by the skull and consists of three parts—the **cerebrum,** the smaller brain or **cerebellum,** and the spinal bulb or **medulla oblongata** (Fig. 102).

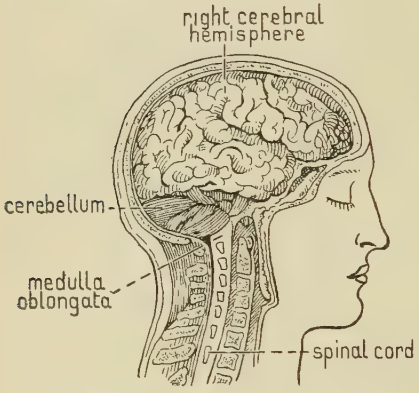


FIG. 102.—SECTION THROUGH THE HUMAN BRAIN.

The large brain or cerebrum occupies most of the brain case, and is composed of two large masses of nervous material known as the **cerebral hemispheres.** Though separate at the surface, they are connected further down within the brain. The surfaces of these hemispheres are thrown into many ridges and intervening depressions which turn this way and that, forming the convolutions, the complexity of which appears to be associated with the degree of intelligence. The human cerebrum has more complex convolutions than those in the brain of an ape, and most of the lower animals, birds, reptiles, etc., have smooth rounded brains, without convolutions.

Consciousness and all that it embraces—thought, will, the emotions, memory, sight, hearing, sensations of pain, etc.—are all intimately associated with a layer of **grey matter,** about $\frac{1}{6}$ inch in thickness, forming the outer portion of the cerebrum. Should this grey matter be injured by accident or altered by organic disease, the mental faculties suffer in consequence, but we must be on our guard against any premature assumption that consciousness is a *product* of chemical or physiological changes taking place in the brain substance. It is quite as reasonable to suppose that the conscious personality is a reality which makes use of the brain as a suitable physical medium for correspondence

with a material world, and that an injury to the brain, the instrument of communication, merely impairs such correspondence with the outside world of ordinary matter. These are subjects that have exercised the thoughts of the greatest intellects of all times, and we are still far from solving these problems.

The interior mass of the cerebrum is composed of white nervous matter, but in the spinal cord the conditions are reversed, the grey matter being surrounded by white substance. The medulla oblongata continues downward as the spinal cord passing through a hole called the *foramen magnum* at the base of the skull. From this part of the brain nerves proceed to various parts of the cerebrum, and it is of great interest to note that the nerves cross over or proceed so that the right side of the brain controls the left side of the body and *vice versa*.

The interesting question arises—are certain faculties, such as speech and vision, controlled by special parts of the cerebral matter; in other words, are there *localised areas of control* in the brain? Examination of the brains of numerous dead persons who, during life, suffered from certain disabilities—defective speech, for example—has shown that certain faculties, such

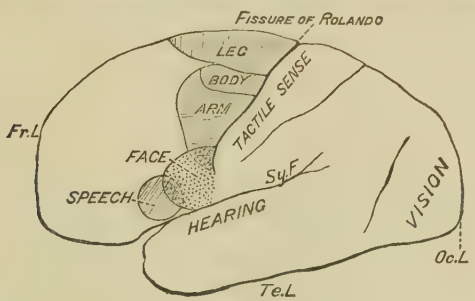


FIG. 103.—LOCALISED CENTRES OF CONTROL IN THE BRAIN.

THE FRONT OF THE BRAIN IS TO THE LEFT.

as speech and vision, are controlled by definite areas of the cerebrum (Fig. 103). Similarly, certain other parts of the cerebral hemispheres are connected with the motor nerves operating the arms, legs, etc. But though the functions of some parts of the

brain are known, as shown in the illustration, there are still large areas of the cerebrum the exact functions of which are still unknown.

The structure of the eye and ear are described in later chapters (XXV and XXVI), and here we are concerned with the general mode of operation of the nervous system.

Nerves are of two kinds, the **sensory nerves,** which extend to the outer surfaces of the body and transmit impressions to the brain, and the **motor nerves,** which send messages from the brain to various muscles so that they move when required. Thus, if you run a needle into your hand the sensory nerves there send a message (painful sensation) to your brain, which then switches on to the correct motor nerves and sends an impulse along them so that your other hand attempts to pull out the offending needle.

The cerebellum or little brain " is concerned with the co-ordination of the actions, nervous and muscular, by which the movements of the body are carried on." In the medulla oblongata and spinal cord are situated centres of nervous tissue connected with ' reflex ' actions, which consist of movements that take place automatically, such as breathing and walking. Once started a person continues walking, though his mind is occupied by thoughts quite independent of his bodily motion.

THE SOURCES OF BODILY ENERGY

Muscular and mental activities, of which our lives are so largely composed, are accompanied by an expenditure of energy, and in order to continue, new stores of energy must be obtained. Energy is obtained from the consumption of food, just as the energy which enables a steam engine to work is obtained from the combustion of coal in the fire box, and the consumption of food is really a cool form of combustion, the oxygen necessary for the process being obtained from the air which enters the lungs.

The digestive system consists of a very long system of tubes which extend right from the mouth to the lower end of the large intestine, together with some very important glands or organs which manufacture certain fluids required for digestion. The chemical processes of digestion commence as soon as food enters

the mouth, where the teeth masticate or break it up, and where the **saliva**, an alkaline fluid secreted by glands below the tongue and in the face, mixes with it. Though the saliva has no action upon proteins or food-stuff such as meat and fish, it contains a ferment called *ptyalin*, which has the power of changing the starch of carbohydrates—potatoes, bread, etc.—into sugar, which is soluble and fitted for absorption into the system. The habit of ' bolting ' food is injurious, because the saliva does not get a reasonable chance of acting upon starchy foods, and because the teeth do not have time to break up the food sufficiently.

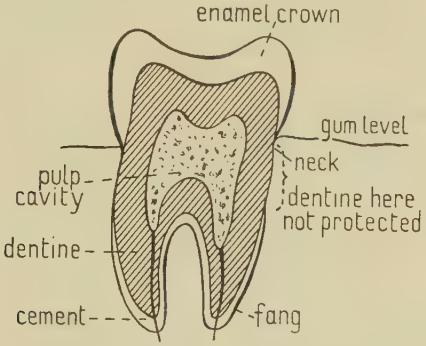


FIG. 104.—A VERTICAL SECTION THROUGH A HUMAN MOLAR TOOTH.

In early childhood we are supplied with a set of ' milk ' teeth, which are later replaced by a second permanent set, 32 in number, including 4 incisors, 2 canines, 4 pre-molars, and 6 molars in the top, and a similar number in the lower jaw. In the centre of a tooth is the soft pulp containing nerves and blood vessels. The larger portion of a tooth is composed of dentine, which is covered by hard enamel on the top or crown, and by cement around the fangs (Fig. 104). But just at the level of the gum the dentine is not covered, and it is just here that bacteria obtain a footing and set up decay unless the teeth and gums are frequently cleaned.

The condition of the teeth is a matter of great importance, since decayed teeth cannot do their work properly and also cause

poisonous matter to be absorbed by the blood, and this kind of self-poisoning leads to bad general health and lack of tone.

When the food has been properly masticated it is pushed by the tongue into the **pharynx,** a muscular bag at the top of the gullet or oesophagus. At the same time the **epiglottis** prevents any material going the ' wrong way ' into the air passage connecting with the lungs. The upper end of the gullet contracts and forces the food a little lower, then that part of the gullet contracts forcing the food still lower, and so on, until it reaches the stomach. This type of muscular contraction which proceeds from one part of the tube to the next part, and so on successively, always in one direction along the tube, is called **peristalsis.** The food after it has left the stomach is also forced along the intestines by peristalsis.

The entrance to the stomach is nearly central (Fig. 105), and a muscular valve or **sphincter** at the end of the gullet contracts and regulates the entry of food into the stomach. The left or cardiac (heart) end of the stomach is dilated or much widened compared with the other or **pyloric** end, where another sphincter regulates the entrance of the chyme or prepared food into the small intestine. The strong muscular stomach is lined with a mucous membrane supplied with blood vessels and a great number of minute glands which secrete the **gastric juice,** a fluid mostly water but containing hydrochloric acid and an enzyme called **pepsin.** The acid which is present in small quantity, about 0·4 per cent., causes the action of the salivary enzyme ptyalin to cease, hence the importance of mastication so far as starchy food is concerned. The pepsin causes the protein substances—meat, eggs, etc.—to be converted to soluble substances called **peptones,** and there are other enzymes which act upon fats. The stomach by means of its muscular contractions churns the food and thoroughly mixes it with the gastric juice, so that after some time, say half an hour, the resulting soup-like material or chyme is ready to be passed into the intestine.

The pyloric sphincter permits only a little at a time to pass forwards, and the action of the stomach continues for some hours until it is time for another meal, when the feeling of hunger warns a person that more food is required.

The upper end of the small intestine is known as the **duodenum** and contains the duct through which the bile secreted by the

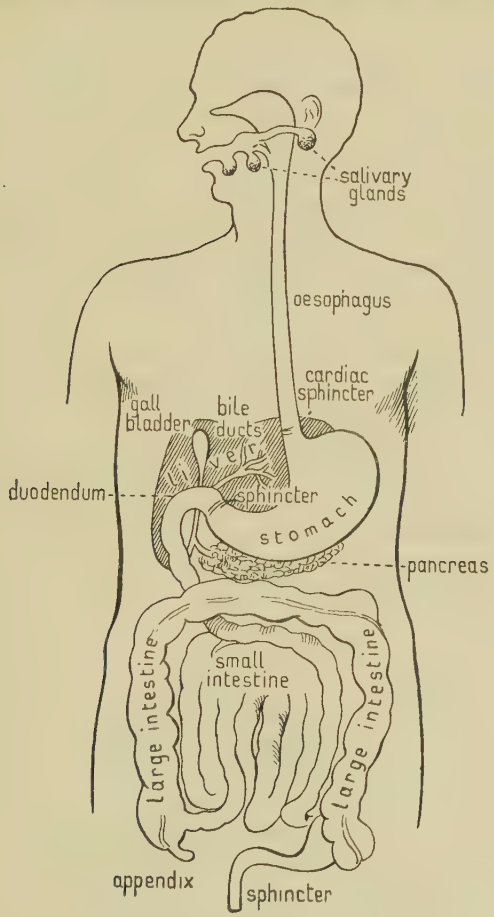


FIG. 105.—DIAGRAM OF THE HUMAN DIGESTIVE SYSTEM.

liver, and the pancreatic juice prepared by the pancreas pass into the intestine. The bile as it comes from the liver is yellow and thin, but later it turns green and becomes thicker. It is stored

in the **gall bladder,** from which it is discharged into the intestine as required. These fluids act upon the chyme by emulsifying the fats in it, that is, breaking them up into minute globules, and by renewing the digestive process of converting starchy matter to sugar, a process that was arrested in the stomach on account of the acid nature of the gastric juice. The addition of fluids from the liver and pancreas renders the material alkaline again.

The food matter is now ready for absorption, and this is accomplished by immense numbers of projections on the inner wall of the intestine termed **villi.** These are furnished with capillary blood vessels which absorb sugar and organic acids, and other minute vessels called **lacteals** which absorb fatty substances. In the larger intestine the process is continued to some extent, though there are no villi, mainly water being absorbed, so that the residue becomes more solid and compact. Any material not absorbed, particularly fibrous vegetable matter, is expelled periodically from the intestine.

There are two muscular sphincters, one at either end of the large intestine, the upper one controlling the passage of food from the small to the large intestine, the other regulating the expulsion of solid waste products from the body. In all there are about 30 feet of intestines, so that they are much coiled and looped in order to fit into the abdominal cavity. They are held in position by a membrane called the **mesentery.**

TYPES OF FOOD AND VITAMINS

It will have been gathered from the description of digestion given above that, chemically considered, there are three classes of foods—**proteins, carbohydrates,** and **fats.** To these certain purifying mineral salts must be added, and of course water.

Proteins are composed of carbon, hydrogen, oxygen, and nitrogen, with some phosphorus and sulphur; they are the source of all the nitrogen which our food contains. As nitrogenous matter is absolutely essential to the building up of new flesh and tissues in a growing child, and to the replacement of nitrogen eliminated by persons of all ages, some sort of protein *must* form part of any person's diet. Nitrogen is eliminated or

removed from the body as urea in the liquid urine expelled periodically. The chief foods of the protein class are lean meats of various kinds, fish, game, eggs, the casein of milk and cheese, and certain vegetable seeds, particularly peas and beans.

Carbon is oxidised and expelled from the body as carbon dioxide in exhaled breath, and to replace this, carbohydrates and fats are eaten. These foods—potatoes, bread, butter, dripping, salad oil, etc.—are mainly energy producing (by oxidation of carbon) and enable us to do our daily work and maintain our bodily temperature ; but it must be understood that proteins also assist in the production of heat, just as carbohydrates and fats to some extent help in flesh building. There is one food, namely milk, which contains all the substances required, even vitamins obtained from the grass eaten by the cow, but for all persons except very young infants a general mixed diet is necessary.

It is estimated that in his daily round of activities an average man loses about $\frac{3}{4}$ of an ounce of nitrogen and $9\frac{1}{2}$ ounces of carbon, besides water and salts. This material loss must be made good, and then there is the loss of heat to be considered. The amount lost daily and therefore the amount that must be made good by the average adult is about 3000 calories, and it must be remembered that these *physiological* or *large* calories are each equal to one thousand of the smaller calories employed in experimental physics.

What sorts of food, and how much of each, does a person require in 24 hours ? The answer to this depends upon how old the person is, and what sort of work he does. Young children require much protein, but, though growing, do not require so much general food as an active adult, and very old people require much less than growing children. Again, a man engaged in heavy manual work needs more than one occupied by work of a sedentary nature, a clerk for example. The daily requirements of an average manual worker include about $\frac{3}{4}$ lb. of lean meat, or its *nitrogen equivalent* in other forms of protein (*e.g.* cheese), carbohydrates equivalent to $1\frac{1}{2}$ lb. of bread, a quarter of a pound of butter or other form of fat, some mineral salts, and at least 3 pints of water. A person need not drink this quantity since many foods contain water in combination.

People living less strenuous lives should eat less than these proportions, and though malnutrition is usually caused by under-feeding, there is considerable illness caused by over-feeding, particularly among middle-aged people living sedentary lives. If the human machine is over-loaded it ceases to run smoothly, the excretory organs have too great a demand made upon them, and the person suffers from self-poisoning.

Sometimes too much of one kind of food may be taken, or stimulants may be taken under the impression that they are foods. The best known stimulants are tea and alcohol, and these substances merely whip up the flagging energies, but one has to pay for it later. No actual food is obtained from these: merely temporary stimulation. Similarly, coffee is a stimulant, but there is a certain amount of food in cocoa.

Now, a person may take plenty of food and yet be ill or under nourished if the materials eaten do not include the necessary amount of certain substances to which the name **vitamins** has been given. Vitamins have not been isolated, but observations and experiments with diet compel us to conclude that certain foods contain minute quantities of some substances which exert a necessary influence upon digestive processes. Without them food is not absorbed properly. Several vitamins have been shown to exist, but some are of more importance than others.

Vitamin A is very necessary for young growing children, for a deficiency of it is the cause of rickets and general debility. This vitamin occurs in milk, butter, suet, the yolk of eggs, herrings, and liver. Both liver and eggs contain all classes of vitamins and are therefore among the very best kinds of food. Cod liver oil contains about 250 times as much Vitamin A as does butter.

Vitamin B, a lack of which produces anaemia (poorness of blood), lack of vigour, nervous debility, and intestinal troubles, occurs mainly in eggs, liver, kidneys, fish roe, heart, wheat, rice, peas, and beans.

Vitamin C is present only in living tissues, hence is obtained from fresh vegetables and raw fruits, oranges, tomatoes, lemons, etc. Tinned and bottled fruits are deficient in this vitamin, and its absence in diet is the cause of scurvy.

Vitamin D is similar in its effects to Vitamin A, and the lack

of it in food leads to rickets and other diseases. In sunless climates it must be included in the diet in order to preserve good health. Milk and butter provide the most important dietetic sources of this vitamin. Cod liver oil is strong in the vitamin, but its unpleasant taste makes it unsuitable for many people. It has recently been found, however, that the vitamin can be produced in a highly concentrated form from a purely crystalline substance, ergosterol, by acting upon it with sunlight or the radiations from a mercury vapour electric lamp, which is rich in ultra-violet rays. Vitamins A and D are now available in concentrated form in solutions, extracts, and pellets and other preparations without having to depend upon cod liver oil, milk, or butter for them.

A word must be said here about cooking. Food is cooked so that it may be softened, made palatable so that it excites the flow of saliva and gastric juice, and preserved when it is cold. Cookery also destroys parasites should any be present. But in some ways cooking may be injurious. Baking destroys vitamins, though boiling may not do so, but in that case they may escape in water strained away from vegetables. The common practice of adding sodium carbonate to vegetables should be avoided, since vitamins are destroyed by such alkaline substances. Finally, it must be stated that one vitamin cannot be substituted for another; all classes must be contained in the food if health is to be maintained.

THE DISTRIBUTION OF FOOD WITHIN THE BODY AND THE REMOVAL OF WASTE PRODUCTS

As we have seen, food substances are absorbed by the blood in minute vessels in the intestines, hence it is the medium by which nutriment is taken to all parts of the body. As in the rabbit, the blood of man consists of a fluid or plasma containing enormous numbers of red cells or corpuscles, and a smaller number of irregularly shaped 'white' corpuscles (Fig. 106). These corpuscles are short lived, the red ones lasting about a fortnight; the white cells last a little longer. New corpuscles originate in the marrow of the bones.

The red corpuscles are coloured by haemoglobin, which contains iron, and are round biconcave discs having no nuclei. They play an important part in taking up oxygen from air in the lungs and carrying it to various parts of the body where oxygen is required. The white or colourless corpuscles (**leucocytes**) appear to operate in connection with resistance to disease. Many of them are constantly changing their shapes, and, as Amoeba envelops food, so these corpuscles wrap around microbes and impurities in the

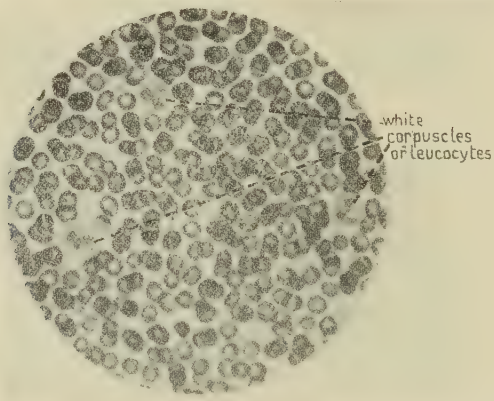


Fig. 106.—A Drop of Human Blood highly magnified.

blood. There are other substances in the blood which assist in resisting diseases, and among these are anti-toxins which neutralise poisons or toxins. The blood thus acts as a policeman as well as a food carrier.

When blood issues from a wound it clots, or coagulates, which is not the same thing as ordinary drying. The blood coagulates because the plasma separates into a fibrous substance called **fibrin** and a yellowish liquid known as **serum**. The fibrin gathers up the corpuscles and the serum is passed to the outside of the clot. In the case of small wounds and scratches the clotting process soon prevents further bleeding, and the application of certain substances such as chloride of iron helps in rapid coagulation.

The total amount of blood in an adult body is about 9 pints, and this is kept pulsating around the system of vessels by the heart. The number of heart beats per minute vary in different persons, an average number for a person at rest being 70. At such a rate of pulsation, about $2\frac{1}{2}$ pints of blood are sent from the left ventricle into the arteries in one minute. Brisk physical exercise and some emotional excitements increase the rate of pulsation.

The four-chambered heart of the rabbit and the circulation of the blood through the arteries and veins have been briefly de-

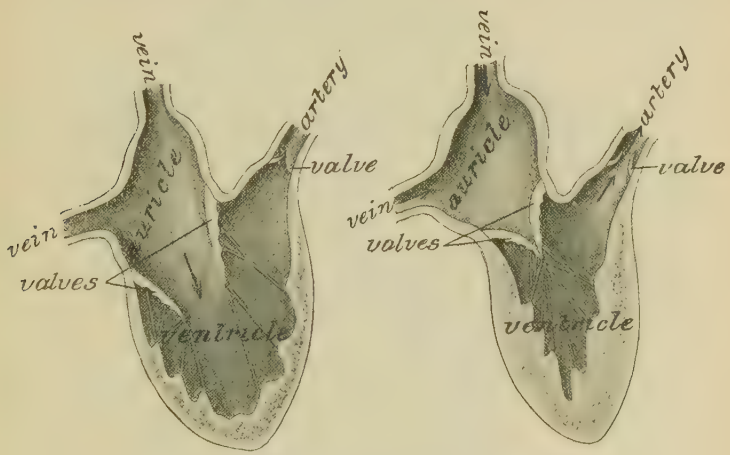


FIG. 107.—SECTION THROUGH ONE SIDE OF THE HEART, SHOWING BLOOD PASSING FROM THE AURICLE TO THE VENTRICLE (LEFT) AND BLOOD BEING FORCED BY VENTRICLE THROUGH ARTERY (RIGHT).

scribed in the previous chapter, and as it is similar to the heart and circulatory system of the human body, an elementary description of this circulation need not be repeated here.

The discovery of the circulation of the blood was made by **William Harvey,** an English physician, who studied first at Cambridge and then at Padua in Italy, where he obtained his M.D. degree in 1602. By careful experiments upon animals and observations upon the valves of the heart, he traced the circulation, and though, at first, other physicians did not accept his theories, his teaching has revolutionised the science and art of

medicine. His discovery constitutes one of the great milestones along the roadway of human progress.

Now the blood is contained within a system of vessels, and we must briefly consider how nutriment passes from the blood to the bodily tissues. A fluid substance called **lymph,** which is formed from the blood material and resembles blood without the corpuscles, passes through the walls of the vessels, and by this means the cells and tissues outside of the blood vessels obtain

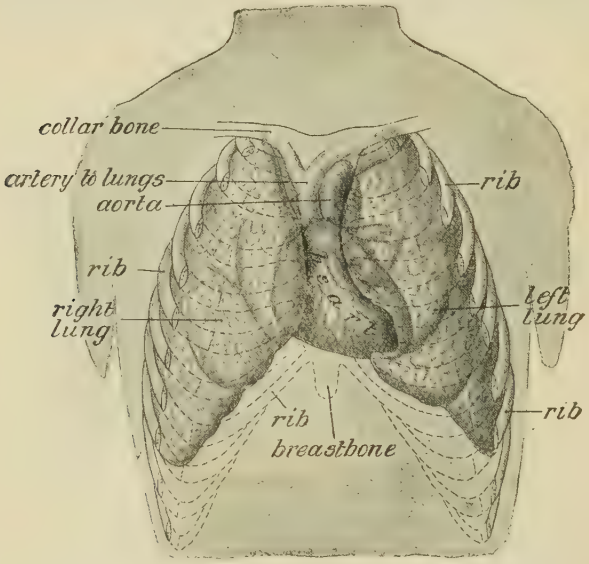


FIG. 108.—THE THORAX, SHOWING POSITIONS OF THE HEART AND LUNGS.

their nutriment. The lymph eventually returns to the blood vessels taking impurities with it. Thus the lymph acts as an agent working between the blood on one hand and the various cells and tissues on the other. The lymph is collected into vessels called lymphatics, but the precise way in which the reunion between blood and lymph is accomplished cannot be described adequately here.

The blood is purified by means of the lungs, the kidneys, and the skin.

The act of breathing, or respiration, is caused by movements of the **diaphragm**, a muscular partition separating the thoracic cavity above from the abdominal cavity below, and the intercostal muscles between the ribs also assist in this work. The rhythmic contraction and relaxation of these muscles vary the size of the thoracic cavity so that an action like that of a bellows is obtained.

The two lungs consist of a branching series of tubes which eventually become a great number of minute passages terminating in little sacs or alveoli. The **trachea** or windpipe gives off two main branches or **bronchi**, one for each lung. The gases, oxygen and carbon dioxide, pass in and out of the blood by diffusion (see Chapter XV) through the walls of the capillary vessels of the lungs.

The kidneys are two large bean-shaped organs, each about 4 inches long, and situated near the back of the abdominal cavity. The blood passing through vessels in the kidney gives up water and urea, a nitrogen compound formed by decomposition taking place in the proteins of the body. The solution containing the urea and certain salts is called urine. Each kidney connects with the urinary bladder by means of a narrow tube called a ureter, along which the urine trickles. A sphincter at the neck of the bladder can be relaxed, permitting the urine to be expelled from the body.

FIG. 109.—HIGHLY MAGNIFIED SECTION OF SKIN,

SHOWING SWEAT GLAND AND DUCT (LEFT), AND HAIR WITH OIL GLANDS (RIGHT).

The skin, as the kidneys, is an excretory organ, that is, an arrangement for throwing certain waste products from the body; and of course it serves as an outer covering for the body. There are two layers forming the skin, an epidermis above and the dermis below. The dermis contains little projections or papillae, blood vessels, and nerves. The skin all over the body contains numerous small openings, each connected by a little tube with a **sweat gland** which secretes water (sweat) containing a small percentage of salt (Fig. 109). The skin is always giving off this

solution, but only during violent exercise or in very hot weather is it inconveniently noticeable. By evaporation of this perspiration the heated body is cooled, so that its temperature is properly adjusted. When the skin excretes a lot of water there is less work for the kidneys to do, but in colder weather the kidneys do more excretory work and the skin does less. Hair and nails are modified portions of the epidermis.

There are numerous other glands in the body, each manufacturing some fluid that has an important bearing upon health and disease, and these will be noted in the next chapter.

CHAPTER XII

MAN'S FIGHT AGAINST DISEASE

MAN has achieved marvellous progress in engineering, industrial chemistry, agricultural biology, and many other branches of knowledge, but by far the greatest benefits that science confers upon mankind are those which enable him to wage a more or less successful war against disease of body and mind, and to increase the average length of healthy life, thus bringing us nearer to the ideal—the greatest happiness to the greatest possible number of individuals.

While realising that workers in the field of medicine and surgery are generally our greatest benefactors, we must not overlook the fact that some of the foremost champions in the lists against disease and ignorance have been, not physicians, but men who would now be called biological chemists, as will be noted later. Indeed, chemistry, physics, biology, and many other subjects, all help in the fight against illness and premature death.

The mechanism of the human body being of a most delicate and complex nature, it is not surprising that at times portions of the mechanism may get out of order, thereby producing ill health. When some part of the body ceases to work properly, though that part is not actually diseased, the person suffers from a **functional disorder,** which under proper care and treatment may right itself, and the mechanism work properly as before. Many forms of nervous trouble are functional derangements of this kind, but perhaps the best known example is ordinary indigestion, due to the gastric juice being either too acid or not acid enough. The stomach does not then function correctly, and in consequence the food is not properly prepared for

assimilation. Medicines can be taken to counteract the condition of the gastric juice, and after a short time the patient usually returns to normal health. But in more serious cases indigestion may result from some actual change taking place in the cells of which the stomach or other organ is composed, and the person is then suffering from a definite **organic disease**, perhaps gastric ulcer, and, of course, the skill of a physician is necessary to diagnose, that is, determine, whether a case is functional or organic in character. There is a very great number of organic diseases, many of which can be communicated from one person to another.

When a disease is passed by contact from a patient to another person the disease is said to be *contagious*. Diphtheria may be communicated in this way. But in many of the worst forms of illness, particularly in those known as fevers—cholera, diphtheria, typhoid, influenza, scarlet fever, smallpox, etc.—the disease is transferred from one to another without bodily contact, when it is said to be *infectious*.

In the process of infection, insects often play a very important rôle. Thus, certain mosquitoes carry the malarial parasite, fleas communicate bubonic plague, the housefly spreads typhoid, and so on (Fig. 110). In other cases, germs in the exhaled breath of a diseased person affect the air so that others breathing that air are infected with the particular form of illness, for example, consumption and scarlet fever. In particular cases, articles of clothing, books, etc., are capable of carrying infection, hence the necessity in these cases of either disinfecting these articles or destroying them. Civilisation, in causing large numbers of people to collect in towns, has assisted in the spread of certain diseases, influenza, for example, but on the other hand, improved knowledge of cleanliness and sanitation has very much lessened the ravages of other diseases, such as typhus, which are fostered by the presence of dirt and

FIG. 110.—TSE-TSE FLY,
THE INSECT WHICH INFECTS PERSONS WITH SLEEPING SICKNESS.

insanitary surroundings. Though rural districts gain in respect to fresh air, and less chance of infection, many lose heavily on account of their antiquated methods dealing with sewage and refuse disposal.

The onward march of civilisation is rapidly tending towards less infantile mortality and greater average length of life, and in order to realise this fact vividly, we have only to consider the condition of medicine and surgery at the time of Napoleon.

OUR DEBT TO SCIENCE

At the end of the eighteenth century practically nothing was known about **bacteriology** or the study of bacteria and other disease germs. That meant that there was no proper knowledge of the cause of the great majority of diseases, and in a large number of cases there was no specific treatment. If diseases are to be treated and prevented the causes must be known.

The rôle played by insects—fleas, mosquitoes, bugs, etc.—was not even suspected, and consequently personal and communal hygiene (health study) was of a low standard. The importance of fresh air was not understood, consumptive and other patients being kept in carefully closed rooms with disastrous consequences. Similarly, the true value of sunlight and ultra-violet rays was not realised.

Nothing was suspected about the influence of certain glands, such as the thyroid, on bodily and mental health. The correct relative values of various types of food and the existence and great influence of vitamins were unknown; consequently deficiency diseases—rickets, scurvy, etc.—due to the consumption of food not containing sufficient vitamins, were rife in towns, particularly among the poorer members of the community.

There was practically no State control of housing, mines, factories, schools, etc., control that has, in modern times, produced most valuable results in general public health.

Surgery was in a similar rudimentary condition. Its state of development can be gathered from the fact that a surgeon was frequently a barber or a chiropodist as well, and was generally

considered much inferior to a physician. To-day, surgery is an art requiring a most exact knowledge of anatomy and considerable manipulative skill, and every medical practitioner must qualify in both medicine and surgery. In the times we are speaking of there was relatively little surgical practice, and many operations, particularly those upon the abdomen, were almost invariably fatal, and consequently not often attempted. Amputations, that is the removal of limbs, were effected, but the stump was either left to take its chance of becoming septic (*i.e.* poisoned) or dipped in tar. As there was very little knowledge of disease germs, the cause of blood poisoning was not understood, consequently there was no **antiseptic surgery,** that is, surgery in which the hordes of injurious germs ready to enter and poison a wound are thwarted by certain disinfectants called antiseptics. Then, blood poisoning often followed an operation and the patient died; now, the patient usually recovers.

FIG. 111.—A MODERN SURGEON IN STERILISED CLOTHING,

INCLUDING RUBBER GLOVES. NOTE THE WHITE WASHABLE WALLS AND MARBLE FLOOR OF THE OPERATING THEATRE.

(*Photo. by Mr. B. Hunt.*)

Operations in those days were awful ordeals compared with operations now, when merciful insensibility is produced by the use of some form of **anaesthetic** (no pain or feeling). Prior to 1840 the patient was commonly given narcotic draughts or excessive doses of alcoholic liquor, so that a sort of stupor was

induced. Even blows on the head were inflicted in some cases. How has science helped us to overcome pain ?

In 1842 **Sir Humphry Davy** suggested the use of **nitrous oxide** (laughing gas) as an anaesthetic for the extraction of teeth ; and about that time the volatile liquid **ether,** which also produces general insensibility or unconsciousness, was first employed. In 1847 **Sir James Simpson** devised safe methods of application, and its use became general. In any operation a separate physician, the anaesthetist, gives the anaesthetic, since its application is a matter requiring skill and experience, particularly when an operation takes a considerable time. The anaesthetic influence of **chloroform** upon animals was noted by a Frenchman named Flourens, but its application to human surgery in 1864 is also due to Simpson, whom we must regard as the originator of modern painless surgery. Another general anaesthetic is **ethyl chloride.** These substances are volatile liquids, and the patient inhales the vapour. In dentistry and some minor operations *local anaesthesia* is produced by the injection of a substance such as **cocaine** into the part to be operated upon. The part becomes insensible, but the patient does not lose consciousness. Since cocaine may produce unpleasant after effects, dental surgeons more commonly employ a substance called novocaine.

In order to understand the immense benefits of both antiseptic surgery and modern medical practice, we must consider briefly certain discoveries made during the last sixty years. Just as we owe wireless communication to the joint labours of men of science and inventors, so progress in bacteriology is the result of patient investigation by many workers, but the foundations of the science and its application have been laid chiefly by two very famous men. The great French biological chemist, **Pasteur,** and the equally famous British surgeon, **Lister,** have conferred upon the human race benefits so great that it is difficult to describe our indebtedness in words.

Louis Pasteur was the son of J. J. Pasteur, a French tanner, and was born on December 27, 1822, at the little town of Dôle in the Jura, though most of his boyhood was spent at the neighbouring town of Arbois. He had considerable artistic

ability, and inherited from his parents thoughtfulness and imagination, two characteristics of great value in scientific research. At the age of sixteen he went to Paris, where he studied at L'Ecole Normale. After some years of study and comparative poverty, he obtained a professorship at Strasbourg in 1849, later he was appointed at Lille, and then at L'Ecole Normale at Paris, where most of his bacteriological work was accomplished between 1857 and 1888.

Pasteur was a chemist and brought to bear upon medical practice a highly specialised knowledge of chemistry, which a physician with a smaller knowledge of the subject and occupied with medical practice could not do. At first, physicians were very much opposed to Pasteur, and regarded his work as being beyond his own province, but eventually truth triumphed, and his researches were eagerly extended by a band of devoted followers, many of them medical men. To-day there are numerous large institutions named *L'Institut Pasteur* in France, Tunis, Algiers, and other places where the work commenced by the great chemist is being extended. The mortal remains of Pasteur himself, who died in 1895, are buried in L'Institut Pasteur at Paris.

The existence of disease germs, or microbes as they are often termed, was known before Pasteur's time, but scientific workers had very confused ideas concerning them ; it was left for Pasteur to crystallise these ideas, to establish the fact that many diseases were due to definite germs, to discover several species of germs responsible for certain diseases, and to find methods of treatment.

How did it come about that a chemist should throw such a flood of light upon **pathology** or the study of disease ?

Some of Pasteur's earlier work included the microscopic study of the vegetable organism yeast (Chapter V) and its influence in causing alcoholic fermentation, that is, the conversion of sugar into alcohol (Chapter XLIII). Then he found that the conversion of alcoholic liquor to vinegar and the turning sour of milk are due to other distinct minute vegetable organisms.

If these bacteria produce changes like fermentation, is it possible for other minute organisms to produce alterations in the blood of animals ? Pasteur answered this question by studying

a disease of silkworms, and found it was due to a distinct minute organism. Evidently a particular disease is caused by a particular microbe. Next he studied the deadly disease called anthrax, which was responsible for the destruction of great numbers of sheep. He proved what others had suspected, that anthrax was due to a definite bacterium, and he effected a means of prevention by **innoculation,** that is, by injecting into the blood a prepared substance or **vaccine,** which enabled the blood to resist the attack of anthrax germs.

The injection of vaccines and other substances called **antitoxins** is now much practised in connection with many diseases, including diphtheria, cholera, tetanus, plague, etc., and in order to understand the principle of the treatment we must go a little further back before the time of Pasteur and consider the work of **Edward Jenner,** a physician of Berkeley in Gloucestershire. It was known before the beginning of the nineteenth century that persons who had suffered from a milder but related disease called cowpox (vaccinia) were *immune* from smallpox, that is, their blood was in some way fortified against the attack of smallpox. About the year 1796, it occurred to Jenner that if persons were treated with an injection of vaccinia or cowpox virus, they would be prevented from having smallpox. Jenner was right, and this special innoculation against smallpox is called **vaccination.** At first Jenner was taken more seriously on the continent than at home, and Germany introduced compulsory vaccination some time before England did. For some years the death-rate or number of deaths per 1000 people from smallpox in Germany was extremely small compared with that in England and France.

Wherever there has been extensive vaccination, as in the armies during the Great War, there has been none or very little smallpox. Now, if that is true of smallpox, why should it not be true of anthrax, diphtheria, typhoid, and many other diseases ? So thought Pasteur, and he endeavoured to find means suitable for the prevention of some of these diseases. He was particularly successful in dealing with anthrax, also with rabies (hydrophobia) the poisoning due to the bite of mad dogs. He discovered suitable vaccines capable, when injected into the blood of the patient, of dealing with these diseases. Vaccines

are generally substances containing either dead or much less virulent germs of the same disease, so that a person develops a mild form of the disease and his blood becomes experienced and capable of dealing with a virulent or more violent attack of the malady. The germs for vaccines are cultivated and kept in suitable media.

Another famous man who must be mentioned in connection with this struggle against bacteria is **Metchnikoff**, a Russian zoologist who worked with Pasteur. He discovered the **phagocytes** or white amoeboid corpuscles of the blood which, by wrapping around the bacteria, consume them. The phagocytes function as the police force of the blood, and once they have had experience of a particular bacterium, they know how to deal with it in future, and the person becomes immune or less likely to suffer another attack of that disease. It is now known that other bodies present in blood serum exert an influence upon the ability of the phagocytes to destroy bacteria, but the explanation of this influence is rather too difficult to be discussed here.

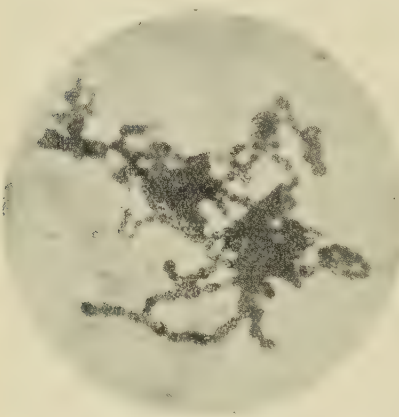


FIG. 112.—CLUSTERS AND CHAINS OF MICROCOCCI, *Staphylococci pyogenes*, × 2000.
(*Photomicro. by P. J. H. Turton, M.D.*)

The germs or microbes against which the phagocytes and antitoxins have to contend may be classified in three structural groups :

Micrococci, or rounded more or less spherical organisms. Examples are the *Pneumococcus*, responsible for the lung disease called pneumonia, and the germs of erysipelas and sepsis or poisoning (Fig. 112).

Bacilli, rod-like bodies. These include the organisms producing diphtheria, influenza, typhoid, leprosy, plague, anthrax,

and many other diseases (Figs. 113 and 114). Certain bacilli are also responsible for the fermentation of milk and cheese.

Spirilla, spiral, twisted, or wavy bacteria. The germs of cholera and relapsing fever are of this kind.

The discovery of these various organisms is the result of investigations by many workers, among the more celebrated being the German bacteriologist, **Koch,** who discovered several germs, including that of tuberculosis or consumption in 1882, and that of cholera in 1883.

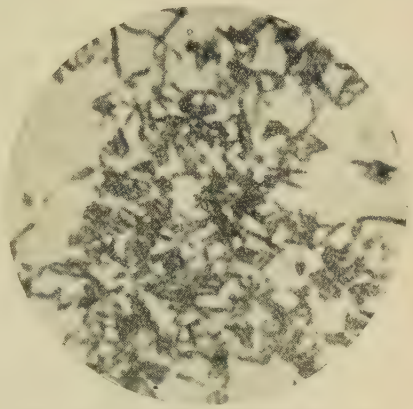


FIG. 113.—*Bacillus diphtheriæ* × 2000.
THE GERM WHICH ACCOMPANIES DIPHTHERIA.
(*Photomicro. by P. J. H. Turton, M.D.*)

Though most disease-producing organisms are minute, unicellular plants (Chapter V), some of the most serious maladies are caused by animal organisms called **trypanosomes.** Thus *Trypanosoma gambiensi* is responsible for the dreaded disease commonly known as sleeping sickness, and in this case an insect, the African **tsetse fly,** acts as a carrier, taking it from one person to another (Fig. 110).

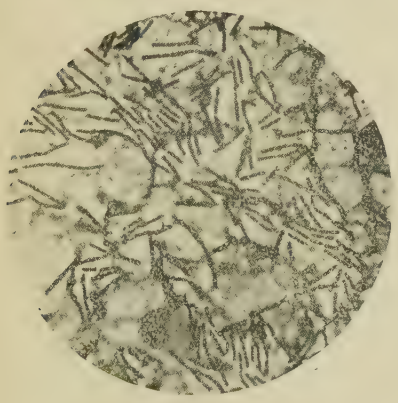


FIG. 114.—*Bacillus anthracis,* × 1000.
THE GERM OF ANTHRAX (WOOL SORTER'S DISEASE)
(*Photomicro. by P. J. H. Turton, M.D.*)

The relation of insects to disease has received a great amount of attention in recent years, and remarkable results have been obtained by **Sir Ronald Ross** and others. It is impossible to do the subject justice in a few words, but it must be

observed that the classic investigations of Ross have shown that mosquitoes carry malarial fever. These insects not only carry the disease germs from person to person but also the germ undergoes essential stages of development within the body of the mosquito. By the destruction of mosquitoes and their larvae, regions formerly scourged with malaria have been made fit for human habitation, a great example of this being the Isthmus of Panama.

Owing to the terrible ravages of yellow fever the earlier attempt to construct the Panama canal was a failure, but since the discoveries of Ross were applied by **Gorgas**, the fever has been

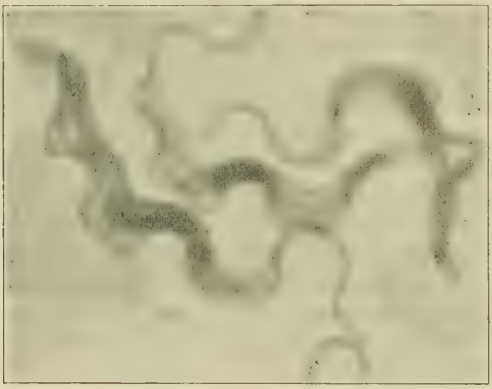


FIG. 115.—TRYPANOSOMES
VERY HIGHLY MAGNIFIED.

conquered and the canal finished. The chief means of removing the mosquito pest consist of draining swampy places and covering water with oil so that the larvae cannot reach the surface to breathe.

Now to return to disease germs in relation to surgery. Joseph Lister, the son of a celebrated optician, was born at Upton in Essex on April 5, 1827. Young Lister studied at University College, London, where he obtained degrees in both arts and medicine. After qualification he became house surgeon at University College Hospital, where he was greatly impressed by the terrible amount of poisoning which affected wounds, and caused death even after quite simple operations. In 1860 he was

appointed professor of surgery at Glasgow University, and here again he was appalled by the great toll of lives taken by sepsis (blood poisoning) among the patients of the Glasgow hospitals.

It was then generally believed that the oxygen of the air was responsible for sepsis, but Lister considered that germs gaining access to the wounds may have been the cause. Assuming this to be the case, the problem he had to solve was how to kill these malignant germs and yet not harm the bodily tissues of the patient. In searching for some suitable substance as a disinfectant or germ destroyer, he noticed that **carbolic acid** took away unpleasant odours from sewage material. He treated wounds with carbolic acid, which formed a crust preventing the entry of germs, and was gratified to find that the wounds so treated did not become septic, and the patients recovered. Eventually the solutions of carbolic were diluted and made less likely to cause injury to the tissues. In Glasgow and other cities, the hospitals, in which great numbers of patients formerly died of sepsis in spite of perfect cleanliness and ventilation, showed great changes in the amount of recoveries obtained.

Lister's work was not confined to antiseptic solutions and wound dressing; he also improved the means of tying up the arteries inside the body when they had to be cut in the process of operation. His methods have revolutionised surgery, and to-day every precaution is taken to prevent germs entering wounds, even the breath and hands of the operating surgeon being screened from the patient's body, and all instruments are *sterilised*, that is, rendered free from bacteria.

Though disease germs are among the most serious enemies of mankind, the practice of medicine is also concerned with many other vital matters. Within recent years a considerable amount of knowledge has been obtained concerning the importance of certain glands in relation to health. Glands are organs the function of which is to manufacture or secrete some fluid necessary for processes taking place within the body. Thus the gastric glands of the stomach prepare gastric juice, and the liver manufactures bile. The liver is a very large organ and secretes something else besides bile. It manufactures a starch-like material known as **glycogen**, and stores it for future use. If plenty of glycogen is

stored in the liver we can do our work well. During periods of excessive work the glycogen is used up. Bile is a secretion passed out from the liver into the intestine, but there are several glands which manufacture *internal secretions* which are passed directly into the blood inside vessels within the gland itself. These internal secretions or **hormones** are now known to exert a great influence upon health and development. A deficiency of the hormone manufactured by the pancreas produces the disease called diabetes, a condition in which sugar that ought to be assimilated is discharged from the body in the urine. Quite recently a Canadian physician, **F. Banting,** has found that if diabetic patients have injections of a preparation containing the hormone extracted from the pancreas of animals they are again enabled to assimilate sugar. This hormone is called **insulin.**

On the top of each kidney is a suprarenal gland secreting a hormone called **adrenalin,** which controls the blood pressure and exerts a beneficial influence upon the nerves of the sympathetic system.

In front of the neck, just below the projection known as Adam's apple, is situated the thyroid gland, which manufactures a hormone having great influence upon growth and development. A deficiency in this hormone produces a dwarf or undersized person called a *cretin.* By treatment with extract of thyroid such cases are greatly improved. But the thyroid gland may produce too much hormone, in which case certain nervous troubles are produced.

It is believed that deficiency in the hormones secreted by other small glands (the parathyroids) situated near the thyroid is the cause of twitching or muscular convulsions and of some kinds of paralysis, accompanied by shaking of the limbs. The influence of two other glands must be noted. The *pituitary* gland, situated at the base of the brain, manufactures a hormone that exerts a powerful influence upon the growth of skeletal structures. An excess of this hormone during the period of youth leads to unusual growth so that the person often becomes a giant, and in adult life an excess leads to unusual enlargement of the bones, particularly those of the hands, feet, and jaw. A smaller body,

the *pineal* gland, at the top of the brain and about the size of an orange pip, secretes a hormone which also has some influence upon the growth of bones.

While many workers have devoted their energies to the study of physical ills, others have made careful observations upon various mental disturbances. Some disorders of the mind accompany a diseased condition of the brain cells, but a great number of mental derangements are due to the action of the mind itself, and are not due to any diseased condition of the matter forming the brain. One of the most striking achievements of recent times is the discovery of an **unconscious mind,** which at times may exert an unpleasant influence upon our conscious minds. The great investigators **Freud, Jung,** and **Adler** have shown that many mental troubles in adult life are due to events which happened in childhood. These events have long been forgotten in the conscious mind, but the unconscious mind forgets nothing, and the events in question may produce an undesirable effect on our conscious mental states. An actual example may make this clear. A certain man experienced unaccountable terror on going into any dark place, such as a tunnel. On careful mental examination by a competent expert, who analysed his mind, or submitted him to **psychoanalysis,** it was found that when he was a small boy he was attacked by a dog in a dark alley. The incident was forgotten by his conscious mind, but unconsciously it exerted its influence and accounted for his apparently unreasonable terror. The cause being explained to him, his terror of the dark disappeared ; he was cured.

Some people shrink from climbing heights, others dread open places, still others dislike persons without any apparent cause, and so on, and these things are due to the influence of events registered in the unconscious. A great variety of cases of harmful unconscious mental activity occur, and a large number of cures have been effected ; but it must be understood that the process of psychoanalysis is of considerable danger except in the hands of an experienced physician who has made a special study of the subject.

THE VALUE OF STATE HYGIENE

Individual persons are units in a more complex organism known as the community or society, and since the health of society is dependent upon that of its individuals, it is of the greatest importance that the State should introduce and enforce laws to maintain the general health of its individuals. Necessary laws are made to compel individuals and communities to observe and take advantage of the facts learned from scientific research.

In the earlier part of last century, young children were put to work in factories and mines; the conditions in factories and workshops were not conducive to good health, ventilation was often bad, rooms overcrowded, lighting was insufficient, hours of work too long, and sanitary arrangements were not as they should be. The **Factory and Workshops Act of 1878** did much to alter these conditions, but this Act was revised and improved by the Acts of 1901 and 1907. According to these laws it is not legal to employ in a factory any person under 14 years of age. Every worker must have at least 250 cubic feet of air space (in many occupations more than this). There must be thorough cleanliness and ventilation or renewal of fresh air, good lighting, a suitable temperature (which varies with the kind of work done), protection from dangerous machinery, proper sanitary accommodation, and a proper means of escape from fire. In order to see that the provisions of these Acts are observed, **inspectors of factories** are employed, and they are at liberty to enter and inspect any factory or workshop at any time. In a similar manner, mines, quarries, chemical works, etc., are controlled by Acts of Parliament and are subject to inspection, though they may be owned by private individuals or companies.

The **Shop Acts** make it illegal to overwork employees, particularly those under 18 years of age.

The young people of to-day are the adult citizens of the future, and very considerable care of the health of children is enforced. Schools are inspected not merely to test the mental progress of the scholars, but also to see that regulations concerning fresh air, ventilation, warmth, safety exits, etc., are properly observed. The personal health of all children attending public elementary

schools is in the charge of a **school medical officer,** a physician appointed by the local Education Authority. Each child is examined at least three times a year, his height, weight, the condition of his teeth, eyes, throat, etc., being noted. In this work a school nurse usually assists, and an attendance officer sees that all healthy children attend school until the age of 14 years. Of course, any suffering from infectious or contagious diseases are kept at home and not permitted to return to school unless certified by a physician that they are not liable to infect other people. Brothers and sisters of a child suffering from measles or other infectious disease must also be kept at home until sufficient time has elapsed to show that they have not contracted the disease. For the sake of public safety the child who is ill is isolated, and the others in the same house are placed **in quarantine**[1] or prevented from associating with others to whom they might carry infection.

The principles of isolation and quarantine also apply to adults in cases of smallpox, diphtheria, and other virulent diseases, the sufferer when possible being taken to an isolation hospital.

Persons disembarking from ships on which infectious disease has broken out and dogs or other animals coming from abroad are also placed in quarantine for a period, since they may be carriers of disease.

The conditions of general health in a district are under the supervision of a **Medical Officer of Health,** who is a physician appointed by the Urban District Council if the district consists of a town, or the Rural District Council if the area is made up of smaller places.

The medical officers for such districts are usually doctors also having private practices, but the County Council appoints a *county* medical officer of health who spends all his professional time in looking after the health conditions of the county as a whole.

The medical officer of a town or county district has many duties to perform. He must investigate the origin and distribution of diseases in his district. Any infectious disease *must*

[1] So called because the period enforced was formerly 40 days.

be notified to him by the doctor attending the case, and he must then visit the place where the disease is, and ascertain that all necessary precautions against its spreading are being taken. The local council looks to him for advice on all matters affecting the health of the district, and when necessary he must give his support to any legal action which may arise concerning such matters. If required he must examine and report upon the condition of milk, meat, and other perishable food-stuffs in shops, etc., and since food is a matter of vital importance, the medical officer

Fig. 116.—A Sewage Works.

may purchase samples of commodities from shops and forward them to be analysed by the public analyst to see if they contain impurities.

The condition of drinking water, the pollution of streams, and the disposal of sewage and household rubbish also come under his supervision, and in this he is assisted by a **sanitary inspector** who reports all cases of nuisance to him.

The disposal of sewage is sometimes effected by means of a **sewage farm,** in which the liquid containing waste matter is allowed to be exposed to and oxidised by the air, the solution then being used to manure the land (Fig. 116). But often the material in sewers is conducted to some convenient stream or

to the sea. Household rubbish is burned in destructors or tipped on to waste land beyond the town.

In many other ways the State endeavours to promote good health among its citizens; for example, one of the duties of the local council is to approve plans of houses and to inspect every house several times during its construction in order to ascertain that the drains, etc., are properly constructed. There are so many ways in which State control is making for good public health that it has been impossible to give anything but a brief outline in this chapter. The results already obtained strikingly demonstrate the value of such control, and these results may be summarised in a single sentence—*the average length of life of the individual is now several years longer than it was fifty years ago.*

QUESTIONS AND EXERCISES

Questions marked C.S.C. *are taken from papers set at Civil Service Commission Examinations, with the permission of the Controller of H.M. Stationery Office ; and those marked* O. and C. *are from Examinations of the Oxford and Cambridge Schools Examination Board.*]

PART I.

ASTRONOMY.

1. Of what is the 'Milky Way' composed ? State what you know of the distribution of stars in the universe. [O. and C.]

2. What is meant by the 'magnitude' of a star ? What 'magnitude' would you estimate the Pole Star to be ?

3. What is a constellation ? Make sketches of any three constellations that you know.

4. What is a spectroscope, and what facts concerning the constitution of the stars have been learned by its use ?

5. Explain how the position of a star may be defined by Right Ascension and Declination.

6. Say what you know of different types of nebulae.

7. What is a variable star ? Give an explanation of one kind of variability.

8. Distinguish between the proper and apparent motions of stars.

9. What do you know of the physical and chemical constitution of the sun ?

10. Describe the appearance of the sun during a total eclipse. Make a drawing to illustrate your answer. [O. and C.]

11. What is a sunspot, and how are the spots distributed over the sun's disc ?

12. What peculiarities with regard to the rotation of the sun are brought out by observations of sunspots ?

13. Why does the moon wax and wane ? What effect does the moon have upon the sea ? [O. and C.]

14. Describe briefly the chief physical features of the lunar surface.

15. What is a planet, and why do the inferior planets exhibit phases similar to those of the moon ?

16. Describe Bode's Law, and state how it led to the discovery of the first asteroid.

17. Say what you know of the comparative sizes and distances from the sun, and the physical condition of Mars, Mercury, and Jupiter.

18. State briefly the history of the discovery of the planet Neptune.

19. Say what you know of comets and meteors.

20. Explain the terms 'latitude' and 'longitude,' and state how they are determined for any particular place. [O. and C.

21. Explain the cause of the seasons experienced in temperate latitudes.

22. What is the difference between solar and sidereal time, and why is solar time employed in everyday life ?

23. Explain the connection between longitude and local time.

24. State what you know of the earth's shape.

GEOLOGY.

1. What is shingle ? Where is it generally found and how is it formed ?

2. By what processes are materials deposited on the sea bottom converted into hard rock.

3. What are limestones, and how are they formed ? Is anything like chalk in process of formation at the present day ? [O. and C.]

4. Give four examples of common stratified rocks, and explain the conditions under which each was formed.

5. What is the origin of coal ? [O. and C.]

6. Compare the type of scenery found in a clay district with that of a hard sandstone area. Give examples.

7. What are fossils, and what light do they throw on the past history of the place where they are found ? [O. and C.]

8. Distinguish between metamorphic and igneous rocks. Mention three examples of each, and explain how they were formed.

9. Define *anticline* and *syncline*. How have these geological features been produced ?

10. What is an *escarpment* ? Where do escarpments occur in England, and of what are they composed ?

11. Write a short essay on the formation of coral islands.

12. What evidence is there to show that active volcanoes have existed in the British Isles in past times ? [O. and C.]

13. Draw a sketch illustrating a section through a typical volcano, and mention volcanic products that are of use to man.

14. Say what you know of the distribution of active volcanoes at the present time.

15. Explain the theory of isostasy, and show how it accounts for earthquake phenomena.

16. What are *consequent* and *subsequent* streams ? Illustrate your answer by reference to the Weald.

17. Outline the evidences of glaciation in the British Isles in past times.

18. In what ways may lakes be formed ?

19. What is the probable condition of the earth's interior ?

20. Describe the processes and results of marine erosion.

21. In what British rocks, and where, are salt, iron ore, coal, and lead ore found ?

22. What are *transverse* and *longitudinal* valleys ? Show the relation of such valleys to railway routes in the Alpine region.

23. What are *kaolin* and *bauxite*, and of what use are they ?

24. Describe rocks which have been formed by the agency of the wind.

BOTANY AND AGRICULTURE.

1. Describe the simple vegetable organism found as a green scum on water tubs.

2. Write a description of the common mushroom.

3. In what ways does a typical plant differ from a typical animal ? [O. and C.]

4. What is chlorophyll ? Explain what is meant by 'photo-synthesis.'

5. Describe briefly the main features of any plant with which you are familiar.

6. What are 'stomata' ? Where are they found and what purpose do they serve ?

7. What do you understand by 'vegetative reproduction' ? Give some examples.

8. Distinguish between the several methods of reproduction by plants. [C.S.C.]

9. What is meant by (*a*) an annual, (*b*) a biennial, (*c*) a perennial ? Give examples of each.

10. Describe and give sketches of the essential organs of any flower with which you are acquainted.

11. How do the following plants reproduce themselves : (*a*) potato, (*b*) dandelion, (*c*) strawberry, (*d*) fern, (*e*) mushroom ? [O. and C.]

12. In what parts of a plant, other than the seed, may food be stored ? Give as many examples as you can, and name the kind of food stored in each case. [C.S.C.]

13. By what various means is the dispersal of seeds accomplished ?

14. What are parasites and saprophytes ? Give examples.

15. Give an account of the part played by water in the life of a plant. By what mechanisms are plants able to avoid too great a loss of water ? [O. and C.]

16. By what agencies is soil formed from rocks ? [O. and C.]

17. Why is chemical analysis of a soil not a good indication of its fertility ?

18. What is meant by an 'artificial manure' ? Name three substances used as such, and point out what are their chief effects. [O. and C.]

19. Why is dung an important manure ?

20. Say what you know of bacteria in soil and the work they perform.

21. Describe the principal changes that take place in the soil when ground is lying fallow, and explain to what they are due. Why is lime often applied to land to increase its fertility ? [C.S.C.]

22. What is meant by the rotation of crops, and what advantages are gained by adopting this system of agriculture ? [O. and C.]

23. What are kainit, superphosphate, and ammonium sulphate, and why is each applied to soil ?

ZOOLOGY.

1. What are corals, and under what conditions do reef builders thrive ?

2. Describe minute organisms the shells of which collect as a deposit on the sea floor.

3. What is a sponge ? Which types of sponge are unsuitable for domestic purposes, and why ?

4. Describe the chief parts of a typical insect.

5. State what you know of the life-history of the common flea. [O. and C.]

6. What is meant by 'metamorphosis' ? Describe the metamorphosis of a typical insect.

7. Write a brief description of the life and habits of the honey-bee. [O. and C.]

8. In what ways are mosquitoes injurious to health, and what means can be employed to minimise the nuisance ?

9. Mention any three insects which are harmful to mankind or to agriculture. What damage do they do, and how would you destroy them ? [O. and C.]

10. How is the cultivation of certain insects beneficial to agriculture ?

11. What is a crustacean ? Describe some crustacean which is used as an article of diet.

12. State what you know of the life history of the eel.

13. What are 'sardines,' and how are they prepared for market ?

14. Describe the chief kinds of edible fish found around the British coasts.

15. State what you know of the migrations of the salmon.

16. Describe the structure of a frog's egg, and trace the changes that

are visible with the aid of a hand lens from the time when the spawn is laid until the little frog leaves the water. [C.S.C.]

17. Make a sketch of a dissection either of a frog or of a rabbit to show the parts of the alimentary canal and the adjacent structures. [O. and C.]

18. Describe the skeleton of the common fowl, and point out differences in its construction from that of a frog.

19. Give a description of a hen's egg. [C.S.C.]

20. Compare the structure of a bird's fore limb with that of a bat.

21. What do you know of bird migration and of the causes to which it is due ?

22. Give a brief description, with a sketch, of the digestive organs of a bird.

23. Give examples of birds which are (*a*) beneficial, (*b*) harmful to agriculture.

24. How are the mouths of birds adapted to different types of food ?

25. What is a mammal ? To which division of the mammalia would you refer each of the following : porpoise, bat, goat, wolf, sloth, cow ?

26. Compare briefly the skull and dentition of a rabbit with that of a dog.

27. Give a description, with sketch, of the heart and circulation of a mammal.

28. What animals supply the following clothing materials : wool, silk, fur, leather ? [O. and C.]

29. How is leather prepared ? Describe the chief varieties of leather and fur.

30. What is meant by respiration ? What is the importance of respiration to both animals and plants ? [C.S.C.]

31. What functions are performed by the brain of a vertebrate animal ? [O. and C.]

32. What do you know of the Arctic whale and the sperm whale, and the useful products obtained from them ?

33. Mention animals which yield : ivory, porpoise leather, isinglass, sepia, pearls. Of what use is each of these materials ?

34. What is a ruminant ? Describe the ruminating process.

35. How does the digestive system of a mammal differ from that of a bird ?

36. What light have fossils thrown upon the ancestry of the horse and of the whale ?

HUMAN PHYSIOLOGY AND HYGIENE.

1. Give the chief parts of the human skeleton.

2. Write what you know concerning the ancestry of man.

3. Describe a movable joint, and explain how it works.

4. By what methods are the activities of the human body controlled ?

5. Draw a diagram of the nervous system to show the different parts of which it is made up.

6. Of what use is the sympathetic nervous system to the body ? Say what you know about it.

7. What do you understand by a reflex action ? Give some examples.

8. What is known about local centres of control in the brain ?

9. Give an account of the human digestive system.

10. What are the chief constituents of human diet ? Why is an exclusive diet of tinned foods harmful ? [O. and C.]

11. What are the advantages and disadvantages of cooking food ?

12. Which classes of food are mainly responsible for (*a*) building new tissue, (*b*) maintaining energy ? Give examples of these classes.

13. What are vitamins ? Mention the chief vitamins, name foodstuffs containing each, and state the result of a deficiency of each.

14. Explain the part played by (*a*) saliva, (*b*) bile, (*c*) gastric juice in the processes of digestion.

15. What are the chief uses of the different kinds of corpuscles of the blood ?

16. Draw a diagram of the circulation, and indicate with arrows the direction in which the blood is flowing.

17. Define ' artery ' and ' vein,' and compare arterial blood with venous blood.

18. Describe the structure of the lungs. How does the oxygen of the external air reach the internal organs ?

19. Explain what is meant by excretion. What organs in the body do the work of excretion ?

20. Write notes on the methods used to eliminate the following diseases : (*a*) smallpox, (*b*) malaria, (*c*) consumption, (*d*) diphtheria. [O. and C.]

21. Say what you know of the life and work of Pasteur.

22. What are hormones, and what influence have they on growth and health ?

23. Give an account of important work in public health carried out by Jenner, Lister, and Ross.

24. Describe the duties of a Medical Officer of Health.

25. Give some account of the means taken to prevent refuse and sewage becoming dangerous to public health.

26. In what ways has legislation improved the conditions in factories and workshops ?

27. What is meant by ' quarantine ' ? Why is it necessary ?

PART II

PHYSICS

MAN'S USE OF MOTION

CHAPTER XIII

GRAVITATION AND ITS USES

THE progress of science depends mainly upon the patient labours of its numerous followers, but from time to time there arises some giant mind which gives the search for Truth a mighty push forward and leaves a colossal landmark along the road to Knowledge. Such was **Sir Isaac Newton,** the great mathematician, who was born in 1642 in the hamlet of Woolsthorpe, Lincolnshire. Originally it was intended that Newton should be, as his father, a farmer, but his interest in mathematics showed that he was destined for a different career, and he entered Trinity College, Cambridge, where he graduated in 1665. Four years later he was appointed Professor of Mathematics in that University.

Newton's earlier work consisted largely of researches on light or optics, and he was in the prime of life, about forty-five years of age, when his great work on gravitation was published. Whether the story of the falling apple is true or not, we owe to him the conception of the master force of the universe, the force that not only causes objects to fall to the earth, but keeps the planets and other heavenly bodies in their places. This great force called **gravitation** is one of attraction, and is capable of acting across apparently empty spaces, resembling magnetism in this respect.

Newton's Law of Universal Gravitation states that: *Every portion of matter attracts or tends to approach every other portion of matter in the universe with a force proportional to the masses and inversely as the square of the distance.* In order to understand this law we need some ideas concerning force and mass. **Force** is that which changes or tends to change a body's motion or disturbs its state of rest. A force may exist though it does not become apparent until objects move. The gravitational force exists before an apple falls from a tree, and only becomes apparent when something causes the tree to lose its hold on the apple. It is the force of gravity which prevents objects, including ourselves, from flying into space as the earth rapidly rotates on its axis.

The **mass** of a substance is the quantity of matter in it, and this quantity is usually represented by its weight. It must be understood, however, that should the force of gravity suddenly disappear, any object would contain the same quantity of matter as before; its mass would be unaltered. The pulling force existing between the earth and an object is measured by the weight of the object, and this force is mutual, each thing pulling the other.

According to Newton's Law, the gravitational force of attraction is less the farther apart bodies are from one another, and this diminution is not simply in proportion to the distance, but *according to the square of the distance.* Thus two bodies two feet apart attract each other with only one quarter of the force they would exert if placed one foot apart. An object falling to the ground becomes nearer and nearer to the centre of the earth as it descends. The distance is constantly lessening and the force is correspondingly increasing according to the law of inverse squares. The increasing force leads to increasing speed or velocity, so that an **acceleration** is obtained. This increase in velocity, which is not merely the rate of fall but the increase in that rate, is a definite extra distance of 32 *feet per second per second*, and this is termed the **acceleration due to gravity**. This quantity is of considerable importance in Physics and is denoted by the symbol **g**.

The significance of this acceleration can be appreciated when it is realised that bullets tossed into the air from an aeroplane

at a great height strike the earth with as great and deadly a velocity as if fired from a machine gun on the ground. The acceleration due to gravity is the same for all bodies, though air resistance influences the general rate of fall. Compare the descent of a parachute with that of a lump of stone. Dissimilar objects fall at the same rate in a vacuum where there is no air resistance.

CENTRE OF GRAVITY

There is a spot in every lump of matter, large or small, such that the whole weight of the lump appears to act from that point. This point is called the **centre of gravity.** In the case of a sphere of uniform composition, the centre of gravity coincides with the

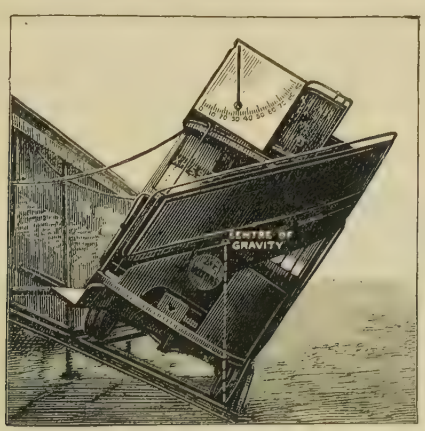


FIG. 117.

A RECENT TYPE OF MOTOR OMNIBUS CAN BE TILTED TO AN ANGLE OF 30° WITHOUT TOPPLING OVER PROVIDED THAT THE WEIGHT OF PASSENGERS IS EVENLY DISTRIBUTED.

geometrical centre of the sphere, and for this reason bodies fall vertically downwards towards the centre of the earth. But in masses of irregular shape, the centre of gravity is at some point determined by the shape of the body. Should the body be composed of various kinds of matter of different relative weights, for example, a lump of limestone containing fragments of lead ore,

then the centre of gravity would be determined not only by the shape but by the distribution of the constituents as well.

In daily life it is important that the centre of gravity of an object does not project beyond its 'base,' otherwise equilibrium is disturbed and the object falls over. Thus, a cart overturns when its centre of gravity projects beyond its wheel base or the area of the ground enclosed by the wheels (Fig. 117). Similarly a person will experience less tendency to fall, when swaying about, if his feet are placed wide apart because his 'base,' the area upon which he stands, is larger with his feet in this position. A flat piece of cardboard can be balanced on a pin point provided its centre of gravity rests on the pin. It is quite easy to find the centre of gravity of such a flat thin object. Two holes are pierced at different corners of the cardboard, and then thread is passed through one hole and the cardboard suspended. If a vertical line is drawn on the cardboard downwards from the point of suspension, the centre of gravity will be somewhere along this line. A weight on the end of a string, or a plumb-line, can be used to see that the line on the cardboard is drawn vertically. The cardboard should next be suspended from the other hole and another vertical line drawn as before. The point where the two lines intersect is the centre of gravity (Fig. 118).

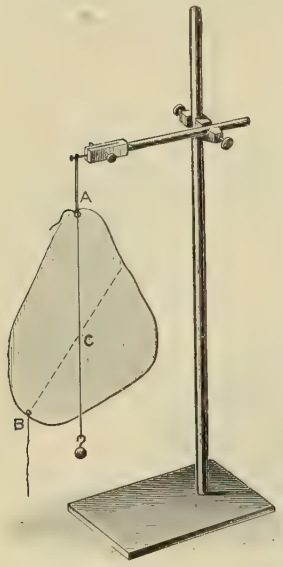


FIG. 118.
A METHOD OF FINDING THE CENTRE OF GRAVITY OF A PIECE OF CARDBOARD.

BALANCES

The principle of most weighing machines consists simply of balancing the weight of an article or commodity against that of standard units of weight. In scientific work where very accurate

results are necessary and where the amount of matter to be weighed is often very small, an exceedingly delicate balance must be employed. This kind of machine is described in the section dealing with chemistry. Any common balance such as that used in a grocer's shop is so well known that it is necessary here to indicate only the conditions of correct weighing. The beam must be properly balanced and consist of two exactly equal portions termed arms. The two scale pans must also be of equal weight, and the whole arrangement must be sufficiently sensitive for a small weight placed on either pan to disturb the equilibrium of the beam.

FIG. 119. A SPRING BALANCE.

Accurate weighing can also be accomplished by means of a spring balance, an apparatus in which the pull of gravity is balanced against the tension of a spirally coiled wire (Fig. 119). An increase in stretch of the wire is proportional to an increase in weight of an object. Thus, a ten pound weight stretches the wire twice as much as does a five pound weight. There is an important difference between the principle of the spring balance and that of an ordinary balance. A pound of sugar would exactly balance a standard pound weight on an ordinary grocer's scales if the arrangement were taken to any place on the surface of the earth. Places are not all equidistant from the earth's centre, so that the force of gravity is not the same everywhere. But the gain or loss of gravitational pull on the pound of sugar would in all cases be equal to that on the standard weight. The tension of a spring balance works differently. At the equator the pound of sugar would stretch the spring a little less than it would do at one of the poles. The sugar would weigh more at the poles than at the equator. *A spring balance gives an accurate measurement of weight, and not merely mass.*

The use of gravitation as a source of power figures largely in daily life, clocks, lifts, and water wheels being operated by it.

CLOCKS

A grandfather clock is a mechanism worked by gravitation in two distinct ways. The fall of weights supplies the force necessary to keep the clock going, while the pendulum swings at a uniform rate so that correct time is kept. The useful properties of a pendulum depend upon certain facts which can easily be verified. If a weight is attached to a string, suitably suspended, and then given an initial push, it will be found that though the weight swings through a distance which becomes smaller and smaller, the time of any one swing is the same as that for any other swing. Count the number of complete swings (to *and* fro equals two swings) during the first 30 seconds, then the number of motions during the next 30 seconds, and so on. Now, if the string is lengthened, the pendulum swings more slowly, making a smaller number of oscillations per minute.

The length of a standard or seconds pendulum which completes a swing in exactly one second in London is 39·14 *inches.* This length is calculated from the point of suspension to a point within the ' bob ' called the centre of oscillation. The average domestic clock is smaller, hence its pendulum beats more rapidly and the clockwork, consisting of geared toothed wheels, must be so geared that correct time is kept.

Experiments prove that at a given place on the earth's surface, the time of swing of a simple pendulum varies directly as the square root of its length.

The intensity of gravity at a place is another factor of the period of swing, and recently much work of an academic nature has been done on the subject of the earth's shape. The vibration period of a standard pendulum of fixed length varies at different places, being longest over the equator and shortest over the poles. This means that the equatorial diameter is greater than the polar diameter of the earth. Hundreds of observations have been made and the mapped results show that the earth is a ball of very irregular shape, even more irregular than an oblate spheroid.

A pendulum exemplifies the fact that energy due to position may be converted to *kinetic* energy, or energy of motion. During

the first half or descending portion of a swing the bob is falling towards the earth, but during the second or ascending half of the motion its acquired kinetic energy carries it upwards against gravitation until the latter pulls it back again. If a heavier substance is used for the bob, does this make any difference to the period of swing? Experiments with equal volumes of iron, wood, and stone show that with a pendulum of fixed length the time of oscillation is not influenced by the weight of the bob. On account of friction with the air, any swinging pendulum gradually comes to rest unless some impulse is given to keep it going. The mainspring of a clock actuates a toothed wheel which engages with two other 'teeth' on a crossbar attached to the pendulum (Fig. 120). This arrangement, called an escapement, enables the spring to give a little kick to the pendulum at the right moment and so keeps it swinging; also by this means the pendulum controls the rotation of the toothed wheel.

FIG. 120.—A SIMPLE PENDULUM AND ESCAPEMENT.

LIFTS

The fall of heavy weights is largely instrumental in the working of cliff railways, lifts, etc. In various mining operations use is made of large buckets or cages which run on wheels down a gently inclined overhead steel cable. Something is not obtained for nothing, so that a certain amount of other power must be used for hauling empty buckets up again. Cliff railways consist of two separate coaches, each standing on a wedge-shaped tank and connected together by a long steel cable passing over large grooved wheels at the top and bottom of the railway. The tank at the top is filled with water, making the carriage at the top of the incline heavier than that at the bottom; when it is released it therefore provides power to pull up the other empty tank and its coach. Again, a certain amount of power must be used to pump water to the required height unless lake or river water

is available at an altitude greater than that of the upper end of the railway. In the case of electrically-controlled lifts, used in large stores, flats, etc., heavy weights function as a counterpoise to balance the weight of the lift itself. Relatively small power is then required to raise the contents of the lift, and this, in an electric lift, is supplied by an electric motor situated either at the top or at the bottom of the deep well in which the lift operates. During descent the motor acts as a brake, preventing undue speed. A measure of safety is supplied by the fact that when the lift gates are not closed the electric circuit is incomplete and the motor will not work.

FIG. 121.—AN ELECTRIC LIFT AS EMPLOYED IN SERVICE FLATS, LARGE STORES, ETC.
(By courtesy of Messrs. Waygood-Otis.)

An interesting psychological effect of lift motion in relation to a person's weight may be observed. When a lift is moving either up or down at a uniform speed, a person experiences the sensation of being at rest while external objects rush past him; but as the lift slows down prior to stopping at the end of a descent, the retardation causes a sensation similar to that of being lifted. Psychologically, retardation downwards is equivalent to an acceleration upwards. Retardation at the top of an ascent causes a sensation of falling to be experienced. Upward retardation is mentally equivalent to acceleration downwards. These sensations are due to the reaction between the lift floor and the person.

WATER POWER

Until relatively recent times the form of apparatus for using the power of falling water was the simple water wheel, and the water was conducted to the wheel by means of open aqueducts or water courses. The wheel was of the overshot type if the water was conducted to the top of the wheel, and undershot if water was taken to the bottom of the wheel.

A greatly improved modern type of machine known as the **Pelton wheel** uses buckets instead of flat vanes and each bucket has a ridge across its middle (Fig. 122). Water from a considerable height is conducted through pipes to a nozzle which ejects it against the median ridge of each bucket in turn. The water is thrown out of any bucket in such a way as not to interfere with the next one. The power obtained depends upon the head of water, that is, the amount of fall, the quantity of water, and the size of the wheel. A Pelton wheel eight feet in diameter will develop 3000 horse-power when the head of water is about 800 feet.

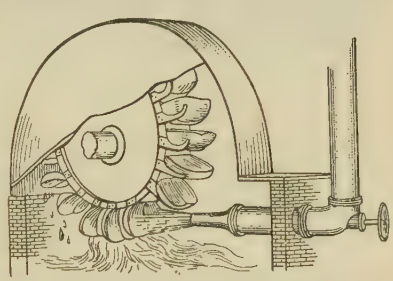


FIG. 122.—A PELTON WHEEL.

A still more recent development consists of the use of water **turbines** in which the water is forced against a series of curved blades connected to an axle, the whole being encased so that the water must pass through the machine. The interaction of the blades and water causes rapid rotation of the axle. Turbines can now be constructed to operate with a fall of water of only a few feet, and it is this type of turbine that must be used in connection with schemes to utilise the rise and fall of marine tides.

TIDES

The mutual attraction between the moon and the earth causes the water of the oceans to be heaped up, as it were, in line with

the moon. As the earth rotates on its axis it carries different places into the position where this bulge of water can occur, so that in turn they experience what is termed **high tide.** It appears to a person situated at one of these places that the tide, or in-

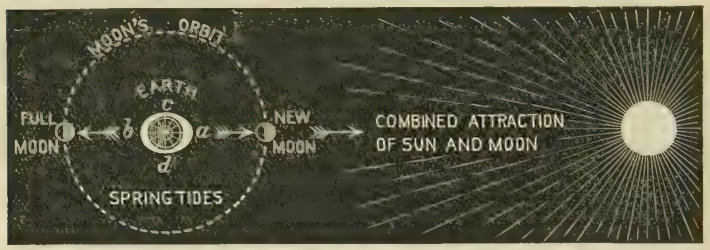


FIG. 123.—THE FORMATION OF SPRING TIDES
DUE TO THE COMBINED GRAVITATIONAL PULL OF THE MOON AND SUN.

creasing height of water, approaches him, but in reality he is moving towards the position where the high tide is produced. When a place has passed the position under the moon the tide falls, and is said to **ebb.** About 12 hours later the same place

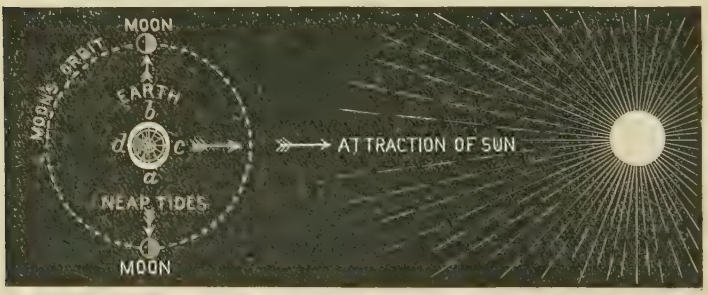


FIG. 124.—THE FORMATION OF NEAP TIDES
WHEN THE GRAVITATIONAL PULL OF THE MOON ACTS IN A DIRECTION AT RIGHT ANGLES TO THAT OF THE SUN.

experiences another high tide as it approaches another position where a water bulge is formed on the other side of the earth. If the moon did not move forward along its orbit there would be two high tides in 24 hours exactly, but owing to this movement of the moon, a place on the earth must rotate through

more than 360 degrees to come again under the moon. Hence there are two tides in 24 hours 50 minutes. When the sun and moon are in the same line, either on the same or on opposite sides of the earth, these two bodies act in conjunction and very high **spring tides** are the result (Fig. 123). Such occur at the time of new and full moon. If the sun and moon are at right angles or in opposition, the forces are opposed, but the moon, though its mass is so much smaller, gets the better of it on account of its proximity to the earth. At these times lower **neap tides** occur under the moon, which then appears as a semicircular disc and is in the position of either first or third quarter (Fig. 124).

Power may be obtained from the daily rise and fall of the tide, but, so far, schemes for this purpose have met with very limited success. Although huge volumes of water may be lifted into reservoirs by each tide, such water is lifted only once in twelve hours, and the *average* uplift is only some ten or twelve feet. The certain periodic rise of the tide, irrespective of weather, is heavily counterbalanced by its slowness, and whether any adequate means of dealing with the matter can be found is a problem for the future to solve.

Many technical problems, alike in mechanical, electrical and hydraulic engineering, still require to be coordinated and solved before a tidal scheme of any large magnitude can be embarked upon with confidence. ' On the other hand,' remarked a writer on the subject in *Nature* of June 3, 1920, ' the possibilities of tidal power, if it can be developed commercially, are very great. Assuming a mean tidal range of only 20 feet at springs, and 10 feet at neaps, and adopting the single-basin method of development with operation on both rising and falling tides, each square mile of basin area would be capable, without storage, of giving an average daily output of approximately 110,000 horse-power-hours. In such an estuary as the Severn, where an area of 20 square miles could readily be utilised with a spring tidal range of 42 feet, the average daily output, without storage, would be approximately 10,000,000 horse-power-hours.'

CHAPTER XIV

MOTION, ENERGY, AND WORK

MOTION may be regarded as that which produces a change in the position of an object relative to the positions of other objects. The motion of a train changes its position relative to the station it has just left, and to the objects it passes as it proceeds upon its way. So many objects encountered in our daily round of activities are so frequently changing their positions relative to one another that the process of living is one in which motion plays a very important part.

Many objects which appear to be stationary or at rest in relation to other things near them are found to be in motion, or changing their positions, when considered in relation to something else. Thus a house appears stationary when its position relative to the ground upon which it stands, other houses, roads, and people passing in and out, is considered; but it, with the ground on which it stands, is changing its position relative to that of the sun and stars.

Similarly, a person sitting in a motor car is at rest so far as the motor car is concerned, but in motion relative to the road and surrounding objects. *Motion and rest are relative, not absolute.*

Let us admit the truth of this statement and proceed to consider certain facts relating to motion and rest as they affect our daily affairs. The garden roller is at rest in the tool shed, and if I wish to roll the lawn I must exert a force to set the roller in motion. The roller is inert until the applied force overcomes its **inertia** and causes it to move.

If in the process of rolling the lawn something occurs which necessitates the roller being stopped quickly, a force has to be exerted to stop its motion. *Its tendency to keep on moving once*

it has been started is also due to inertia. Hence inertia may be defined simply as the tendency of a body to remain as it is either at rest or in steady motion (Fig. 125). The planets have been revolving around the sun during many millions of years because of their inertia; it would require an inconceivably great force to stop their motions. The earth continues to rotate on its own axis for the same reason. But on the surface of the earth the objects we have to deal with do not move for ever once they are set in motion. Many attempts to produce a machine capable of perpetual motion have been made but none has succeeded. The enemy of motion is **friction**, due to the rubbing of one object against another. Even a gas, such as the air, is capable of producing friction with objects rushing through it. Meteoric fragments proceeding at great speed through the upper air become white hot as the result of friction. Beyond the upper limits of the atmosphere in vast spaces devoid of ordinary matter the planets keep 'the even tenour of their way' because of their own inertia and the absence of friction.

FIG. 125.—AN EXAMPLE OF INERTIA.

AS THE TRAIN, WHICH IS TRAVELLING IN THE DIRECTION OF THE ARROW, SUDDENLY SLOWS DOWN A HANDBAG MAY BE THROWN FORWARD BY ITS TENDENCY TO KEEP IN MOTION.

A considerable force is required to start the motion of a roller, that is, to give it an **acceleration**, but once started no force would be necessary for continued motion if it were not for friction. As it is, sufficient force must be applied to overcome this friction. The amount of friction in any case depends largely upon the nature of the surfaces in contact, upon the shape of such surfaces, and upon the weight of the objects. In general, the smoother things are the less the friction. Very little force is required to produce motion in the case of a man skating upon ice, but con-

siderable force is necessary to drag a heavy box along the ground.

In a great many ways friction is a hindrance and means have to be employed to lessen it. Lubricants, such as grease and oil, are applied to moving parts of machinery, but in many applications the method of reducing friction consists in the use of either spherical or circular surfaces. Ball bearings afford an example of the former (Fig. 126) and a wheel is an example of the latter. Such devices lessen the number of points of contact and result in friction due to rolling and not to sliding. *Rolling friction is less than sliding friction*, other things being equal, and in hard steel wheels on steel railway lines we have an example of friction

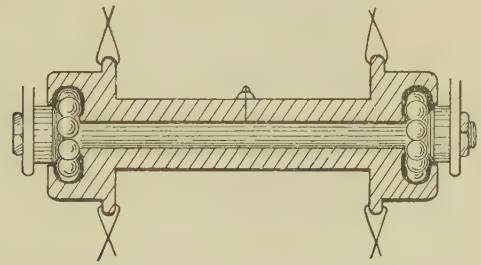


FIG. 126.—SECTION OF THE AXLE OF A BICYCLE WHEEL.
SHOWING BALL BEARINGS TO REDUCE FRICTION.

reduced to a practical minimum. Though friction is often an obstacle, it must not be overlooked that without friction life as we know it would be impossible. The actual friction between the wheels and the rails is necessary to start a train's motion. Similarly with walking, friction between our feet and the ground is a necessary condition of forward motion, and friction is required to stop trains, motor cars, and other objects in motion. It is also the principle on which the action of the clutch of a motor car depends (Fig. 127).

Inertia plays a very important part in many ways. Though it is a hindrance when we wish to start a machine or move an object, it is a great advantage once a machine has been started. For example, the moving flywheel of an engine possesses considerable inertia in virtue of which energy is stored up, and the

engine keeps working steadily although the power is actually applied intermittently. As in the case of friction, the greater the weight the greater the inertia, hence a heavy flywheel takes much more force to start it, but will also require much force to stop it.

Other aspects of motion must now be considered. At the commencement of its motion a train moves slowly, the pull of the engine being used to overcome friction and inertia, but very soon it moves more quickly, and its motion is said to be accelerated. The acceleration is measured by the number of feet per

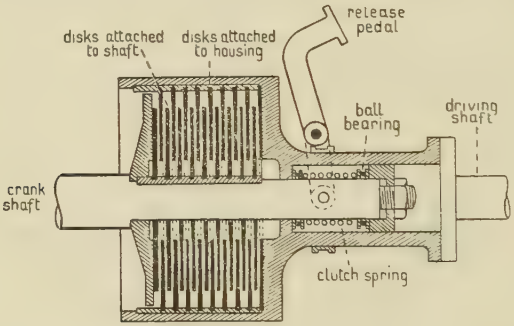


FIG. 127.—THE CLUTCH OF A MOTOR CAR.

FRICTION BETWEEN THE TWO SETS OF DISCS COMMUNICATES THE MOVEMENTS OF THE ENGINE TO THE SHAFT OF THE CAR. THE DRIVING SHAFT CAN BE FREED FROM THE ENGINE CRANK SHAFT, AS IN CHANGING GEAR, BY SEPARATING THE DISKS BY THE 'RELEASE PEDAL.'

second by which the velocity is increased. In the previous chapter it was shown that under the influence of gravity a falling object has an acceleration of 32 feet per second per second, but a train's speed accelerates at a much slower rate, about $\frac{1}{5}$ foot per second per second. The rate of motion of a train or other moving object irrespective of the direction of motion is known as **speed,** and the term **velocity** applies not only to the rate of motion but also to the direction as well.

A moving body acquires **momentum,** and the amount of momentum depends upon the amount of matter or mass of the object and its velocity. Thus **momentum = mass × velocity.** If two bodies travelling in opposite directions collide, the one having the smaller momentum will be pushed backwards by the other one. A large flywheel on an engine has more momentum than

a small one composed of the same material though both are moving at the same speed.

If two flywheels of exactly equal mass are moving at different speeds the momentum will be greater in the one having the greater speed. Practical applications of momentum are numerous, a pile-driver, which is essentially a large heavy weight employed for driving wooden poles into the ground and an ordinary hammer being other examples.

FORCE, ENERGY, AND WORK

It is by no means easy to define the exact nature of **force**, but anyone can realise what is meant by the statement that it requires force to move a garden roller. A force must be applied to an object if we wish to do any one or more of the following :

(1) Disturb the object from a state of rest or steady motion. (2) Increase its rate of motion. (3) Overcome friction and keep it moving at the same rate. (4) Alter the direction of its movement. (5) Stop its motion once it has been set going.

A railway train may illustrate any of these applications of force. The first three are obvious, and an example of No. 4 occurs as a train is rounding a curve, the force between the rails and wheels causing an alteration in direction. The application of the brakes to stop the train illustrates No. 5.

Another example of a force changing the direction of motion is afforded by gravitation, which has caused the planets to revolve around the sun in elliptical orbits instead of proceeding along straight lines.

Common personal experience shows that more force is required to give the same acceleration to a larger mass than to a smaller mass. Also it is clear that with an object of given mass it requires more force to move it quickly than to move it slowly. Combining these factors we have,

Force = mass × acceleration, a law formulated by Newton.

When two forces act in different directions upon a body, that body will move in a direction and with an acceleration resulting from the combination of the two forces ; hence we speak of the resultant force and acceleration. Simple problems on such

combinations of forces can be solved graphically by the **parallelogram of forces.** The resultant force urging a ship forward when pulled by two tugs A and B is of such magnitude and direction that it is represented by the diagonal OR of the parallelogram OBRA (Fig. 128). Of course it is important that the lengths and directions of the lines OA and OB represent correctly the amount and direction of the force exerted by tugs A and B respectively.

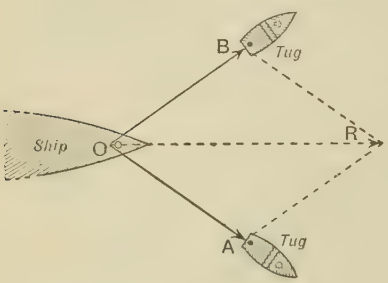


FIG. 128.

THE SHIP WILL MOVE IN THE DIRECTION *OR* AS THE RESULT OF THE FORCES EXERTED BY THE TUGS *A* AND *B*.

A force causes an object to move, and in virtue of that motion the object possesses **energy,** and such energy due to motion is said to be **kinetic.** A weight, such as that used in a grandfather clock, possesses energy because of its position, and this is known as **potential** energy.

In either case, kinetic or potential, *energy is the capacity to do work.* The kinetic energy of the piston in the cylinder of a gas engine does work in operating various machines in a factory, and the potential energy of the falling water at Niagara does work in operating the dynamos which generate electricity (Fig. 129).

Anything capable of doing work is regarded as a form of energy, and when necessary one form of energy can be converted to another form before certain useful work is performed. Let us trace the various transformations of energy and the kinds of work performed in the case of an ordinary steam engine connected to a dynamo for the generation of electricity. The coal in the fire box burns because it has a chemical attraction for oxygen of the air, and this chemical attraction has energy which develops heat, another form of energy. This heat does work in changing water to steam, which then expands and exerts a pressure, so causing the piston to move and acquire kinetic energy that does work in forcing a wheel to rotate. The wheel being connected to, or *coupled* with, the armature of a dynamo, the latter also moves and electricity is generated. Such elec-

tricity can then be taken along wires and made to do useful work such as operate tramcars, light lamps in houses, cook meals, electroplate various objects, etc. Since chemical attraction, heat, and electricity are capable of doing work, they also are forms of energy.

So is gravitation, and in engineering practice the capacity of an engine for doing work is expressed in terms of the weight it

FIG. 129.—AERIAL VIEW OF NIAGARA FALLS,
WHERE IN FOUR DEVELOPMENTS ON THE ONTARIO SIDE ALMOST HALF-A-MILLION HORSE-POWER IS INSTALLED.
(By permission of the Director, Department of the Interior, Canada.)

can lift against the force of gravity. The fundamental unit employed is the **foot-pound,** or the amount of work done in lifting a one pound weight through a vertical distance of one foot. **James Watt,** the inventor of the steam engine, found that a horse could raise a weight of 150 lb. through 220 feet in one minute. Hence the *practical unit* of **one horse-power = 33,000 foot-pounds per minute.**

The *average* amount of manual work done by an active man is equal to $\frac{1}{8}$ horse-power: the engines of motor cars vary in horse-power from 7 to 30; gas engines, employed in factories to operate machinery, range from $\frac{1}{2}$ to 200 horse-power, while the maximum horse-power of a large first class battle cruiser is about 120,000. The unit 'horse-power' is generally written as H.P.

It is quite easy to calculate the amount of power required to perform a simple type of work. Thus, suppose we have to find the power which must be exerted to lift a hundredweight of coal from the road to a flat 30 feet above ground level. The foot-pounds necessary are $112 \times 30 = 3300$, and this is a little more than $\frac{1}{10}$ of a horse-power if the act of carrying the coal up this distance takes exactly one minute. Should the work require only 30 seconds, the same energy has been used in half the time, and the power exerted is just over $\frac{1}{5}$ H.P. This is the power required to *raise the coal only*; in reality the man also lifts his own body through the same distance, and this requires more power. During a short period a man can expend energy at a much greater rate than $\frac{1}{8}$ H.P.

When one form of energy is converted to another for our convenience, a certain amount of energy is wasted though not destroyed. Thus falling water can be used to drive turbines and so generate electricity, but we do not obtain all the foot-pounds in the form of electricity. A considerable percentage of the original energy is converted to heat on account of friction between the parts of the machinery and this heat is of no practical use. If 70 per cent. of the original energy is obtained in the form of electricity, we say that the machinery has an efficiency of 70 per cent. The wasted 30 per cent. of the energy is not destroyed but is simply not harnessed for practical purposes. *Though energy is often wasted it cannot be destroyed, neither can it be created*, the sum total of energy remains unchanged, a fact briefly described as the **conservation of energy.**

MECHANICAL ADVANTAGE AND SIMPLE MECHANISMS

Since energy cannot be created, how is it that the small force exerted by a man can raise a very heavy weight quite easily when

he uses a simple arrangement called a **lever,** consisting of a long rod and a pivoting point or **fulcrum** about which the rod turns ? If the man is to raise the heavy weight, the distance from the fulcrum to the weight must be much less than that from the fulcrum to the man's hand. When this is the case, the man's arm moves downwards through a big distance as the heavy weight moves upwards through a small distance. A small force moving through a larger distance equals a larger force moving through a smaller distance in the same time. The lever has given the man a **mechanical advantage** in permitting him to make use of distance,

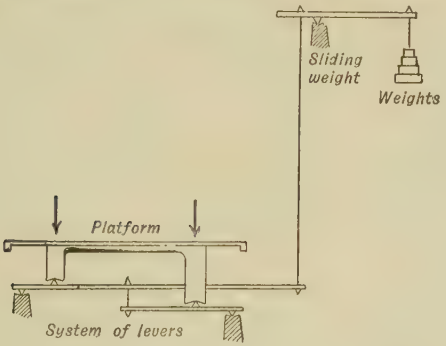


FIG. 130.—DIAGRAM OF A PLATFORM WEIGHING MACHINE USED AT RAILWAY STATIONS.

and the greater the ratio of the distance through which the man's hand moves to that through which the weight moves (called the **velocity ratio**) the greater the mechanical advantage obtained. Their distances depend upon the position of the fulcrum. Suppose the fulcrum to be placed one foot from the heavy object and six feet from the man's hand, then theoretically the mechanical advantage should be six, and a weight of three hundredweight should be lifted by a continued hand pressure equal to 56 lb. Actually the mechanical advantage is a little less than 6 owing to loss of efficiency through friction. Since the man's hand moves through six times the distance the weight moves through in the same time, the velocity of the hand is six times that of the weight ; the velocity ratio is six.

A simple lever may be used to balance unequal weights placed

at different distances from the fulcrum, the lesser weight being at a greater distance than the heavier one. On a seesaw a small child weighing four stone placed nine feet from the fulcrum balances a twelve stone man situated only three feet from the fulcrum, and as they move up and down the child will move through three times the vertical distance the man moves through.

A chemical balance and an ordinary grocer's scales are arrangements in which there is no real mechanical advantage

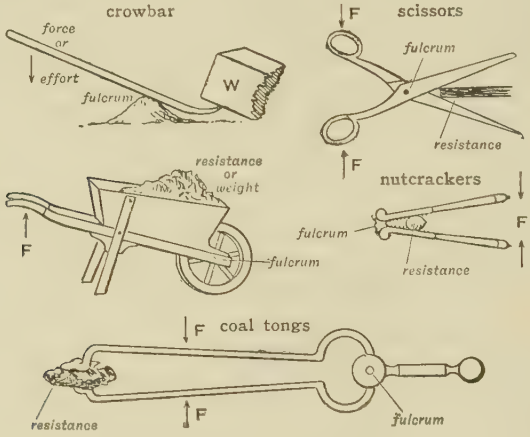


FIG. 131.—EXAMPLES OF COMMON OBJECTS WHICH FUNCTION AS LEVERS.

since the weights on both sides are equal, but in the machine for weighing luggage at a railway station considerable advantage is gained by a system of levers so that quite a small weight balances a large one (Fig. 130). The weighbridge in the road outside a station, and used for weighing trucks of coal, etc., also consists of a platform resting on a system of levers, so that a big mechanical advantage is obtained and relatively small weights balance the load.

Three classes of levers are recognised according to the relative positions of the force, the fulcrum, and the load or weight. If the fulcrum is situated between the force (F) and the weight (W), the lever is of the first class, an example being a crowbar, while a pair of scissors is a double lever of this class. (Fig. 131.)

In levers of the second class the weight comes between the force and the fulcrum, as in a wheelbarrow and in a crowbar, using the ground as a fulcrum. A pair of nutcrackers is a double lever of this class. When the force is applied between the fulcrum and the weight the lever is said to be of the third class, a pair of coal tongs being a double lever of this type.

A little consideration will enable a student to classify the following for himself: pump handle, tin-opener, pair of bellows, address stamper, a bird's wing, a door hinge.

Other means of obtaining mechanical advantage are afforded by **screws, wheels,** and **pulleys.** In an ordinary winch used for drawing water from a well, the handle moves on a much larger circle than that of a point on the cylindrical drum upon which the rope winds or unwinds itself. Consequently a smaller force on the handle can balance a larger force due to the weight of water being lifted, and the mechanical advantage is determined by the relative radii of the two circles, that described by a point on the cylinder and that described by the hand.

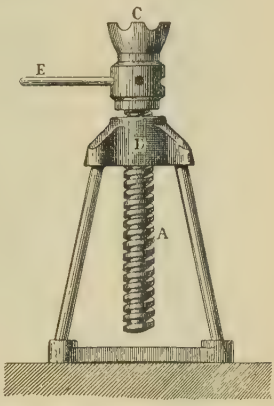


FIG. 132.—A SCREW JACK.

The principle of an ordinary screw is somewhat similar. The lower part of a screw possesses a spiral groove called a *thread*, and the vertical distance between two consecutive turns of the thread is called the step. One rotation of the screw forces it into a piece of wood a distance equal to the step, and the mechanical advantage obtained equals

$$\frac{\text{circumference of circle described by the hand}}{\text{step of screw}}$$

from which it follows that a screwdriver having a wide handle gives a bigger mechanical advantage than one with a small handle.

An office letter-copying press is a good practical application of the principle of the screw.

An ordinary **jack** for lifting the wheel of a motor vehicle

consists of a smaller toothed wheel meshing with a larger wheel connected to a vertical screw ; many turns of the smaller wheel result in fewer turns of the larger wheel and slower turning of the screw, hence the mechanical advantage is very great and very heavy loads may be lifted. A simple type of screw-jack is illustrated by Fig. 132.

In building and engineering operations heavy masses of stone, steel, etc., are raised into place by means of an arrangement of wheels and chains (or ropes) called a **pulley**. For very

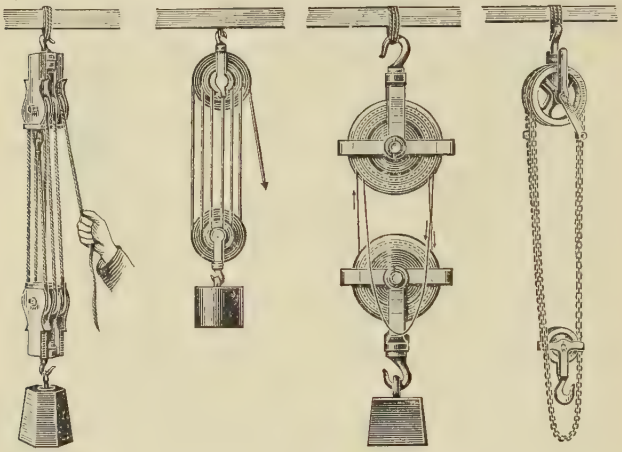


Fig. 133.—Various Types of Pulley.

heavy materials the pulleys are attached to cranes and worked by engines.

The simplest kind of pulley consists of a rope passed over a grooved wheel suspended from a strong overhead beam or support. If a weight is attached to one end of the rope, the weight can be raised, but there is no mechanical advantage. If a weight of 56 lb. is raised one foot, the man exerts a continued pull of 56 lb. through one foot. Since it is easier to pull downwards than upwards, a certain physiological or muscular advantage is gained and that is all. But if the number of grooved wheels is increased a mechanical advantage can be obtained.

By causing the rope to pass over several wheels, as in a builder's single rope pulley, distance is again employed, and a smaller weight (or pressure) moving through a larger distance can raise a heavier weight through a small distance. The mechanical advantage obtained depends upon the number of wheels employed; if this be four, then theoretically the mechanical advantage is 4, and so on, with this class of pulley, but it must be remembered that friction and the weight of fittings always mean a certain loss of efficiency. Another type of small but powerful pulley used by builders employs an endless chain.

Another means of reducing the force required by increasing the distance is that known as an **inclined plane.** If a body is to be moved to a position higher than its present level, say a distance of 100 feet, it can be moved vertically, or it may be caused to move along an inclined surface the length of which is greater than the vertical distance of 100 feet. It will require less force per second to move the object up the inclined plane than that required to move it vertically. The mechanical advantage of such a plane is determined by the ratio of its length to the height. The practical application of this principle is more common than any form of lever or pulley, since any gradient on any roadway or railway line is an example of it. A person ascending a ladder or a staircase, and trucks ascending slopes in mines are other examples.

CHAPTER XV

MATTER AND SOME OF ITS PROPERTIES

The various objects which form the external world around us, also our own bodies, are composed of some sort of substance or **matter.** We appreciate the reality of these objects because we perceive them through our senses—touch, sight, hearing, smell, and taste. Of course any one object does not usually affect all of our senses, but we see and feel most things. Substances which are invisible may be felt or smelt, as in the case of a stream of coal gas issuing from a jet; others may be felt only, for example, a moving mass of air commonly called a wind. Sometimes substances, such as diffused coal gas or poisonous sewer gas, may be perceived only through the sense of smell. Taste is generally associated with sight and touch when we eat our food. In all these cases we become aware of the existence of matter because it produces sense impressions in our minds. Hence matter may be defined as *the external reality equivalent to certain sense impressions experienced by us.*

Very little consideration is necessary for us to realise that there are **three physical states** assumed by matter—**solid, liquid,** and **gas**—extremely common examples of each being stone, water, and air respectively. It must be observed that the solid, liquid, and gaseous states are *physical* conditions, and the same substance may exist in any one of these forms. Thus ice, water, and steam are all the same thing so far as the sort of matter is concerned, but the physical states are different. Many other varieties of matter met with in daily life may exist in any of the three physical states, the chief controlling condition being temperature, though pressure is another factor which must not be overlooked. With ordinary conditions of temperature and

pressure any substance exists in one state, solid, *or* liquid, *or* gas. Air is normally gaseous, but if the temperature is lowered sufficiently it becomes liquid, and if a still lower temperature is produced it becomes solid. The great majority of common substances are solid at ordinary temperatures, but by heating them sufficiently many of them may be converted to the liquid and gaseous states. Thus ice, sulphur, and wax are easily liquefied and vaporised, but on the other hand such materials as rock and carbon remain solid even at high temperatures, though at sufficiently high temperatures even rock is liquefied, as in volcanic eruptions, and carbon becomes gaseous (Chapter XLII).

Metals become liquid at fairly high temperatures, though pure tin melts at the relatively low temperature of 232° C. Water, oils, and mineral acids are examples of materials normally in the liquid state.

Though most substances in changing their physical state pass from solid to liquid, and then from liquid to gas, there are a few materials which proceed straight from the solid to the gaseous state, or on cooling pass straight from vapour to solid. The nearly black glistening substance called iodine is an example. In certain granite areas crystals of copper and tin ore are found as mineral veins traversing cracks in the surrounding rocks. Similarly lead ore and barytes, a mineral used for the manufacture of paint and other purposes, occur as veins in limestone regions. All these substances are insoluble in water, and so cannot have been deposited from water solutions, as rock salt and some other minerals have been. It is believed that heated vapours containing compounds of tin, copper, lead, and barium were, on cooling, changed directly from vapour to solid without an intervening liquid state.

MOLECULES AND THE DISCONTINUITY OF MATTER

If your foot collides violently with a large lump of granite you become painfully aware of the fact that the granite is impenetrable so far as your foot is concerned. But is it impenetrable as regards every other kind of matter? Experiments upon

rocks of various kinds, including granite, show that they contain numerous minute spaces or pores capable of containing water or other substances possessing the power of penetrating into them.

There are many reasons for believing that even substances such as iron and steel are not so compact as they appear to be. The behaviour of matter causes us to assume that any body is composed of a vast number of minute units called **molecules** and that these molecules are not in contact with one another but are separated by intermolecular spaces. *Matter in all its forms is discontinuous.* The molecules are so small that they cannot be seen even with a high power microscope, but we realise that they are there all the same. The study of heat compels us to believe that the molecules are not only separated by spaces but also are in constant motion, a fact which explains why a gas always fills a space. The relative distances between adjacent molecules, or in other words the freedom for motion of the molecules, is related to the physical state of a substance. In solids the molecules are nearer together than they are in either liquids or gases, and in gases they are very much more widely separated than they are in liquids.

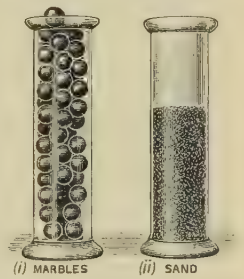


FIG. 134.—AN ILLUSTRATION REPRESENTING INTERMOLECULAR SPACES.

THE SAND IN THE SECOND VESSEL CAN BE MADE TO OCCUPY THE SPACES BETWEEN THE MARBLES IN THE FIRST VESSEL.

Several important properties of matter are the direct result of this variation in the dimensions of the intermolecular spaces. In solids the molecules are not so free to move about, hence solids are more or less *rigid* and are capable of retaining any sort of shape in normal circumstances. A cube of sugar remains a cube—its molecules do not flow in various directions; even a piece of clay retains its shape unless special force is exerted to alter its form. These facts can be stated differently by saying that *a solid is capable of retaining any number of free faces*, that is, faces or surfaces unaffected by the walls of a containing vessel. A cube of sugar placed in a cup is still a cube; its faces or surfaces retain their individuality as it were. Now

in a liquid the molecules are more widely spaced and are much more capable of motion, hence *the liquid is not rigid*, and when placed in a vessel *it has only one free face, its upper surface, and this is always horizontal.* With the exception of this one free face its shape is moulded by the containing vessel. The molecules of a gas are still more widely spaced and more free to move, so that *a gas always fills a containing vessel whether the pressure upon it is great or small, and there are no free faces at all.* Some idea of the relative freedom of molecules in a gas may be obtained from the fact that a cubic foot of water on being boiled gives 1600 cubic feet of steam at the usual atmospheric pressure.

Both liquids and gases are termed **fluids** because they are not rigid—their molecules are free to flow easily from one position to another—but it must be noted that different liquids exhibit different degrees of **mobility** ; in some, such as water, the particles are more mobile than those of others, for example treacle, which exhibits a greater degree of **viscosity.**

It can be shown quite easily that liquids such as water contain spaces between the molecules. If some water is placed in a measuring glass, its surface level noted, and then some common salt is placed in it, the salt disappears or **dissolves** without raising the level of the water. The salt in dissolving distributes itself regularly among the spaces between the water molecules, so forming a **solution,** and the water is described as a **solvent.** The solvent property of water is of great practical importance, as pointed out in later chapters ; but as examples of such useful aqueous solutions, we may here refer to various medicines, thermal and medicinal springs, chemical and photographic reagents, electrolytes for electroplating, certain solutions used in chemical industries, dyeing, brewing, etc. A few water solutions are a nuisance, one of the more common examples being that of bicarbonate of lime obtained from limestone districts. This substance (and others) renders the water hard, so that it must be softened by various means (see Chapter XXXIV) before it can be used in steam boilers and laundries.

These properties of water are due to the fact that it is porous ; in reality it is much more porous than many solids of the same dimensions. There are other solvents besides water. Thus

the liquid called acetone dissolves the gas acetylene used for house lighting ; substances such as resin and wax dissolve in alcohol, and many solids insoluble in water dissolve in dilute acids, though in this case a chemical change takes place before solution is accomplished. Some liquids can dissolve in other liquids ; for example, oils dissolve in alcohol, and as in the case of

FIG. 135.—MINING SALT.
THE SALT IS DUE TO FORMER SOLUTION AND EVAPORATION.

dissolved solids, such a solution results from the intermolecular spaces of one liquid being occupied by the molecules of the other.

If clear water is carefully placed in contact and above another liquid, say a purple solution of potassium permanganate, for a short time, the heavier, coloured liquid remains below and they appear separate, but very soon they commence to interpenetrate and finally form a mixture of uniform colour. The molecules of each have occupied the interspaces of the other by a process known as **diffusion.**

Gases also diffuse in this way; any gas in attempting to fill a given space occupies the interspaces of another, and such a mixture may be of an explosive character, as when air is mixed with from 5 per cent. to 14 per cent. of coal gas. If gases did not diffuse, they would arrange themselves with a lighter one above and a heavier one below, and explosive mixtures would not be so easily formed. Diffusion of gases proceeds at different rates, and it has been found that the lighter the gas, the more quickly it occupies the spaces between the molecules of another gas. Diffusion explains why a heavier gas, such as carbon dioxide in a vessel surrounded by lighter air, will partly leave the vessel and ascend into the air, while some air descends into the vessel and mixes with the remaining carbon dioxide. The spread of such gases among the particles of air is a cause for the necessity of good ventilation in rooms and mines.

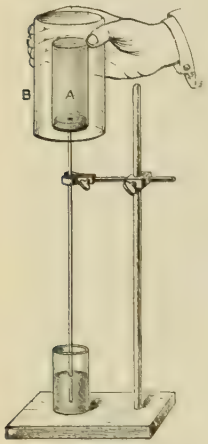


FIG. 136.—AN EXAMPLE OF DIFFUSION OF GASES.

HYDROGEN IN THE POROUS VESSEL *A* DIFFUSES INTO THE AIR IN *B* WITH THE RESULT THAT WATER RISES IN THE TUBE.

When two liquids or two gases are separated by a solid porous partition such as parchment or unglazed earthenware, diffusion through the partition takes place and the process is then known as **osmosis.** Practical consequences of osmosis are of some importance; for example, water passes through the cell walls of the root hairs of plants as explained in Chapter V., and in some forms of electric battery an earthenware porous partition is employed to separate certain substances, at the same time permitting hydrogen gas to pass through. Substances dissolved in water may be divided into two classes—**crystalloids,** like common salt, which easily diffuse through a porous partition, and **colloids,** such as white of egg and glue, which do not pass at all, or do so with difficulty.

CAPILLARITY AND SURFACE TENSION

The particles forming a piece of wood are held together by a force of attraction ; they are said to **cohere.** The particles of a liquid do not cohere so well as do those of a solid, and in a gas the cohesion is not apparent at all. When a piece of glass or one's finger is dipped in water, on withdrawing the finger some water **adheres** to it, hence the term adhesion refers to the attachment of particles of one kind of matter to an object composed of another kind. Certain facts relating to cohesion and adhesion are of interest. If you place your finger in mercury instead of water, particles do not adhere to your finger, because in mercury cohesion is stronger than adhesion. In water the reverse is true; hence most objects dipped in it and then withdrawn are made wet.

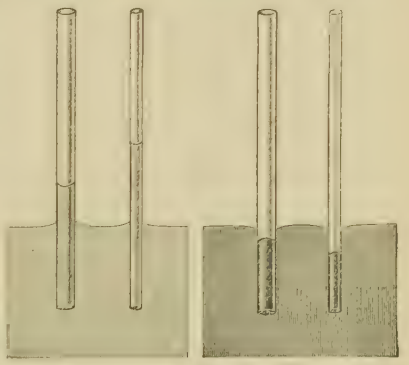


FIG. 137.—CAPILLARY TUBES.
WATER STANDS ABOVE, MERCURY BELOW, THE OUTER WATER SURFACE.

If a glass rod is placed in water, the surface of the water against the rod is curved upwards instead of remaining horizontal because the force of adhesion is greater than that of cohesion. When a piece of glass tubing is employed instead of a rod, water also rises inside the tube, and if the latter is very narrow the water will rise a considerable distance. (Fig. 137.) The water in the tube is first curved upwards, then tends to straighten itself horizontally again, then curves upwards a little farther, and so on, until the weight of the little water column exerts a pressure sufficient to stop further horizontal straightening. This process of a liquid creeping upwards in a narrow tube is termed **capillarity,** and the narrow tube is called a **capillary** tube. Oil ascends the wick of a lamp, or melted wax rises in the wick of a candle by this process. Specimens of a patient's blood are sent in sealed capillary tubes to bacteriologists for examination to see

if certain disease germs are present. Capillarity is also responsible for the upward motion of water in muslin or similar fabrics, and is one of the factors producing the movement of water upwards through the stems of plants.

Liquids, particularly water, behave as if a fine skin covered the surface, such a skin effect resulting in the spherical shape assumed by *small* drops of water as in rain and dew. The sphere has the smallest surface area for a given volume of liquid and is, when possible, the shape assumed when a surface behaves as if it were composed of stretched rubber. **Surface tension,** in causing the water to assume the least surface possible, is thus responsible for the spherical form of small drops. In larger volumes the surface tension is too weak to balance the weight, which causes the water or other liquid to assume the form of flattened globules. The tendency of surface tension to form rounded drops is well illustrated by water slowly dripping from a tap. (Fig. 138.)

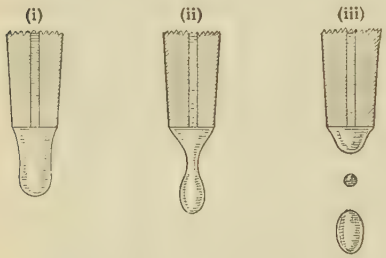


FIG. 138.—SURFACE TENSION OF WATER.
STAGES IN THE FORMATION OF A DROP.

ELASTICITY

If a glass or steel ball is dropped upon a hard stone floor it rebounds nearly as high as the position from which it was dropped, but a piece of stone scarcely rebounds at all. Why is this? When the glass marble strikes the floor it is slightly flattened at the point of contact. (Fig. 139.) But it strongly resists this flattening and immediately regains its former shape with the result that it kicks off from the ground. The stone exhibits only a feeble tendency to recover its shape, so it does not push off with anything like the same force. The tendency to recover original shape is called **elasticity,** and glass is much more elastic than stone. Indiarubber or 'elastic' makes elasticity apparent, but it is not nearly so elastic as glass or steel.

Certain disturbances known as wave-motion (see Chapter XXII) proceed more quickly in substances having a marked degree of elasticity. Thus sound waves pass much more quickly through steel than through wood, and a tuning-fork used in music is made of steel because its rapid oscillations result from the high degree of elasticity. At times earthquake waves pass through the centre of the world right from one side to the other in about twenty minutes because the substances forming the inside of the earth are more rigid than steel and possess a greater degree of elasticity.

FIG. 139.—ELASTICITY OF A GLASS BALL.

ON STRIKING THE GROUND THE BALL IS DISTORTED, BUT IT IMMEDIATELY RECOVERS ITS SHAPE AND REBOUNDS.

Both liquids and gases exhibit **elasticity of volume**; that is, they show a marked tendency to recover their original volume when a compressing force is removed. In this sense a gas, so long as it is not near the temperature at which it liquefies, is perfectly elastic, the volume always recovering its original dimensions exactly when the pressure again becomes exactly as it was before. Liquids behave in a very similar manner, but there is this important difference: whereas gases can be compressed to a very minute fraction of their original volume if the pressure is sufficiently great, liquids are only slightly compressible. No matter how great the pressure exerted upon water, its volume is decreased by an extremely small amount.

The Pacific Ocean is in places more than five miles deep, so that the pressure near the ocean floor must be enormous. In spite of this, however, the density of deep oceanic water is only very little more than that of the surface water. The very slight compressibility of water plays an important part in the transmission of pressure in such appliances as hydraulic presses and lifts described in the next chapter.

CHAPTER XVI

WATER PRESSURE AND BUOYANCY

Iron, wood, and other substances do not sink through an ordinary solid material, such as a table top, for the simple reason that the particles of the solid table do not move aside and make way for the object to sink through it. The particles of a fluid, however, such as water or air, are capable of moving out of the way, so that an object heavier than the fluid, bulk for bulk, sinks. Thus a piece of iron sinks through water and through air, but a piece of wood does not sink through water, though it does through air, because a certain volume of wood, a cubic foot for example, is lighter than a cubic foot of water, but heavier than a similar volume of air.

Evidently the factor which determines whether an object sinks or floats in a fluid is the weight of a definite volume of the object compared with the weight of an equal volume of the fluid.

Since water is so plentiful on the earth's surface and mankind is so much concerned with it in shipping and other ways, the relation of liquids to solids immersed in them is best illustrated by special reference to water, though it must be understood that the same principles are generally applicable to other liquids.

BUOYANCY AND SHIPPING

As we have just seen, a cubic foot of iron sinks in water, because it weighs more than a cubic foot of water. This fact can be stated in another way. The iron sinks because a cubic foot of it contains more matter than that in a similar volume of water, the matter constituting iron being *denser* than that composing water. The **relative density** of iron is greater than that

of water ; the density of water being taken as unity, the relative density of iron is 7·8. It is an easy matter to prove that iron is 7·8 times as dense and as heavy as water, all the evidence required being the volume of a lump of the metal expressed in cubic centimetres and its weight expressed in grammes. Then *by dividing the weight by the volume the relative density is obtained*, as the following example shows. A small piece of iron weighs 10 grammes and its volume is found to be 1·3 cubic centimetres. Now 10 grammes of pure water have a volume of 10 cubic centimetres, and by dividing weight of water by its volume we get 1 as the relative density of water. It requires only 1·3 c.c. of iron to weigh 10 grammes, and by dividing weight by volume we obtain 7·8 as the relative density of iron.

It is easy to weigh a piece of iron, but its volume cannot be determined by measuring length, breadth, and depth when the piece is of irregular shape. In the case of insoluble substances heavier than water, the volume can be found by immersing it in water and noting the displacement. This can be done by means of a measuring glass graduated in centimetres, the levels of the water before and after the immersion of the substance being noted and the difference gives the volume in cubic centimetres.

The weight of any substance, or the force of gravity upon it, is directly proportional to its relative density, hence the term **specific gravity** is used to denote *the ratio of the weight of a substance to that of an equal volume of pure cold water*. Thus the quantity 7·8 represents both the relative density and the specific gravity of iron. Similarly the specific gravity (and relative density) of common glass is 2·5, that of limestone is 2·6, that of lead is 11·36, and so on. These facts can be verified by the method given above.

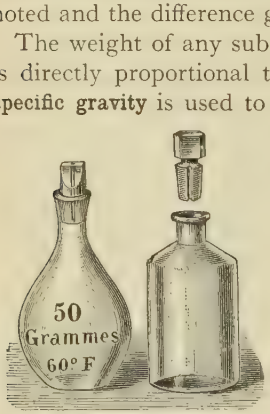


FIG. 140.—SPECIFIC GRAVITY BOTTLES.

In the case of sand, lead shot, etc., a simple apparatus called a **specific gravity bottle** is used (Fig. 140). The bottle has a glass stopper containing a narrow tube passing through it so that water can flow out of the tube and ensure that the bottle

is completely filled with liquid. The method of procedure is as follows: (1) weigh the sand; (2) weigh the stoppered bottle filled with water together with the sand (outside the bottle) on the same balance pan; (3) place the sand in the bottle, fill up with water and weigh again. This third result will be less than that of (2) since water is displaced by sand, and the loss in weight (*i.e.* 2 - 3) gives the volume of the sand, and the specific gravity is found as usual.

Since specific gravity of a substance

$$= \frac{\text{weight of a definite volume of substance}}{\text{weight of equal volume of water}},$$

that of a liquid can be found simply by filling the bottle with the liquid and weighing, and then by filling the bottle with pure water and weighing again. As the volume is the same in each case, the required specific gravity is the ratio of the weight of liquid to that of water.

We are now in a position to state in more precise terms the reason why an object sinks or floats in water. Any object having a specific gravity greater than that of water sinks in it, but one having a specific gravity less than that of water floats in it.

An iron ship floats because its volume is composed largely of air and light objects occupying the various rooms and spaces. The specific gravity of the ship *as a whole* is much less than that of water, but should a bad leak occur the ship sinks immediately the specific gravity of the whole exceeds that of sea water. A lifeboat composed of very light materials does not sink though it may become filled with water, because the specific gravity of boat plus water still remains less than unity.

It is very necessary to load ships so that there is a sufficient margin of safety; it is dangerous to allow the specific gravity of the whole to approach too near to that of water. Until the year 1890 ships were often overloaded and unable to withstand heavy seas; since they were immersed too deeply in the water there was not a sufficient **freeboard** or part of the ship above the water line. A native of Bristol named **Plimsoll** eventually succeeded in getting it made illegal to load ships so that they floated too low in the water, and now every ship bears a mark called the **Plimsoll**

line which determines the level of its greatest permissible submergence (Fig. 141). Since sea water varies in composition and density, slightly different levels are permitted in different seas.

The cargo-carrying capacity of a ship is represented by a figure called its **tonnage**, an estimate of which is arrived at by dividing the number of cubic feet of space by 100. That of the *Majestic*, the world's largest liner, is about 56,500 tons, and this means that it can carry this amount of material; but a heavier battleship of the super-Dreadnought type, such as H.M.S. *Hood*, can carry only a smaller load of some 40,000 tons because of the great quantities of steel and iron in its construction; it does not require so much additional weight to bring it down to the

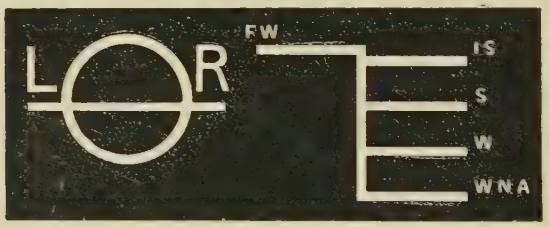


FIG. 141.—THE PLIMSOLL LINE

WHICH IS MARKED ON THE SIDES OF ALL SEA-GOING VESSELS. THE LETTER LR REFER TO LLOYD'S REGISTER OF SHIPPING. THE LINES TO THE RIGHT INDICATE CORRECT LEVELS FOR *Fresh Water*, *Indian Summer*, *Summer in temperate latitudes*, *Winter*, and *Winter in North Atlantic*.

Plimsoll line. A **submarine** may be regarded as a ship having a variable and controlled specific gravity. Tanks are arranged fore, aft, and amidships, and by means of water admitted to these the vessel sinks when desired. On the water being expelled again by pumps worked by compressed air, the ship rises to the surface.

The human body has a specific gravity slightly greater than unity, hence to prevent its sinking one of two things must occur. Either it must attach itself to a buoy, so that the specific gravity of body-plus-buoy is less than that of water, or by movements of the limbs in swimming a sufficient upward pushing force is exerted. The motions of arms and legs in swimming force the body upwards as well as move it forwards. As explained below,

such an upward force or *upthrust* is equivalent to a loss in weight.

Owing to the different proportions of dissolved salts in sea water in different regions, the body and other objects vary in buoyancy in various seas. Average sea water has a density of 1·0275, that of the Baltic is less dense than this, but that of the Dead Sea in Palestine is greater, a fact which explains why the human body floats in the Dead Sea. It is much easier to swim

FIG. 142.—ICEBERGS FORMING FROM A GLACIER.
ICE BEING ONLY SLIGHTLY LESS DENSE THAN WATER, MOST OF AN ICEBERG REMAINS BELOW THE SURFACE OF THE SEA.

in salt than in fresh water, because less force is required to prevent the body from sinking.

Since water expands on freezing, ice is less dense than water, consequently it floats, but only about one-ninth of its volume appears above sea-level, the greater submerged portion being a source of considerable danger (Fig. 142). Oils float on water and do not mix with it, a fact which explains the use of oil to make rough water calmer and incidentally is responsible for the saying, 'pouring oil on troubled waters.' It seems that the oil acts as a

lubricant preventing the wind pushing or dragging the water up into dangerous crested waves. It may also suppress small ripples by reducing the surface tension, thus aiding the calming process by giving the wind still less ' grip ' on the water. The fact that oil floats on water is also made use of when it is poured on water containing mosquito larvae ; it prevents the larvae from reaching the surface to breathe, so that they die of suffocation.

HYDROMETERS AND THEIR USES

Liquids such as oil, turpentine, methylated spirit, and alcohol have a relative density less than that of pure water, hence their specific gravities are represented by fractions less than unity. This being the case, an object which just floats in water will sink in one of these liquids. A piece of wood floats in water with part of its substance above the water line, but the same piece of wood is submerged to a greater extent if placed in methylated spirits, hence *the relative amount of submergence of a special object can be used to determine the specific gravity of a liquid*, the special object employed being called a **hydrometer.** This normally consists of a glass tube containing air and correctly weighted with a little mercury at the bottom, so that the instrument floats upright in pure water with so much of it submerged that the correct reading on a scale coincides with the surface of the water. If the instrument is now placed in a less dense liquid, such as turpentine, more of it is submerged and the specific gravity can be read directly from the scale (Fig. 143). Such hydrometers are of two types—those used for ascertaining the specific gravities of liquids lighter than water, and others employed with liquids heavier than water, suitable scales being employed for each purpose.

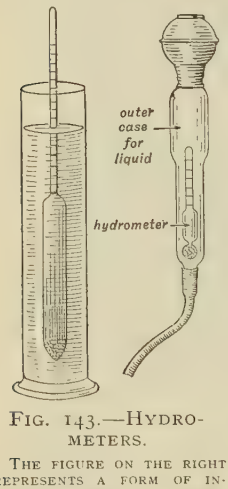


FIG. 143.—HYDROMETERS.

THE FIGURE ON THE RIGHT REPRESENTS A FORM OF INSTRUMENT USED FOR TESTING SPECIFIC GRAVITY OF ACID IN ACCUMULATORS.

There are many practical uses of such instruments, for example, the determination of the specific gravity of acid in an accumulator. When the accumulator is in the fully charged condition the hydrometer indicates about 1·25, but when discharged the acid solution is less dense and the reading is roughly about 1·18. The density of milk can be tested by means of a special hydrometer graduated for the purpose and called a **lactometer.** The average specific gravity of good cow's milk is 1·031. Similarly, other hydrometers are used to determine the relative densities of beer, spirits, etc. Proof spirit is a mixture of water and alcohol having a specific gravity of 0·9198 at a temperature of 15° centigrade. Spirits which are underproof contain less alcohol and consequently have a higher specific gravity.

THE PRINCIPLE OF ARCHIMEDES

It is easy to find the volume of metal or stone by displacement of water on a measuring glass, but how are we to find the volume of a substance such as sand in order to calculate its specific gravity? Another method in which volume can be found by *weighing* is employed, and in order to understand this method we must consider other facts concerning bodies immersed in water.

When a stone or other object is completely submerged it *displaces a volume of water equal to its own volume*, and this displaced water resents the displacement as it were, and exerts a pressure or upthrust, trying to force the stone out of the water again. The force of gravity pulls the stone downwards, but the effect observed is not so pronounced as when the stone is weighed in air, since there is opposition due to the upward pressure of the displaced water. In other words, *the stone loses weight when it is immersed and the amount of this loss is equal to the weight of displaced water.* Now, every gramme of displaced water means one cubic centimetre of volume, hence the loss of weight in grammes equals the volume of displaced water in cubic centimetres, and this equals the volume of the completely submerged object. *The volume of any insoluble solid can be found by noting its loss of weight when immersed in water.* This

relation between the loss of weight and volume, and known as the **Principle of Archimedes,** was discovered by **Archimedes,** a Sicilian mathematician who lived about 250 B.C.

Instead of placing a piece of stone or iron in a measuring glass containing water, its volume can be found by weighing it first in air as usual, and then in water by suspending it with a thread and submerging it in water contained in a vessel supported on a wooden bridge. (Fig. 144). The vessel and water is thus kept apart from the pan of the balance as shown in the illustration.

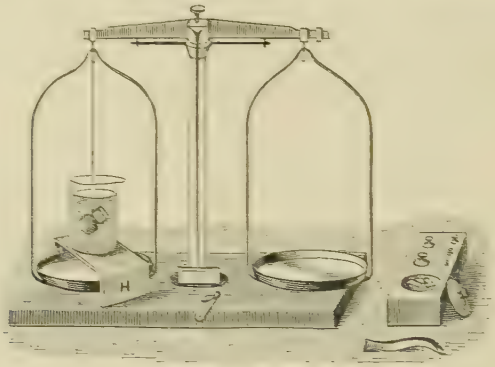


FIG. 144.

AN INSOLUBLE OBJECT MAY BE WEIGHED IN WATER CONTAINED IN A VESSEL SUPPORTED ON A BRIDGE, *H*, ABOVE THE BALANCE PAN.

The Principle of Archimedes enables us to consider the matter of buoyancy from still another aspect. An object sinks as soon as the upthrust due to displaced water is insufficient to keep the object afloat. The Plimsoll line is a means of ensuring a sufficient margin of effective upthrust. It must be clearly understood that when an object sinks the upthrust is still there, but is not successful so far as flotation is concerned.

SOME PRACTICAL CONSEQUENCES OF WATER PRESSURE

The level of water in a vessel is raised when some of it is displaced by an immersed solid. The water raised above the

original level exerts a downward pressure, and this pressure is transmitted in all directions, as explained in the previous chapter. Thus the water in a tank presses as much on the side as on the bottom of the tank. One result of this distribution of pressure is the level or 'horizontal' surface of undisturbed water. In popular language this fact is frequently expressed by the statement that 'water finds its own level.'

Pressure on the sides of anything containing water is responsible for the breaking down of artificial dams and natural embankments called levees with accompanying disastrous floods. If water did not press upon the sides of a tank a hole could be

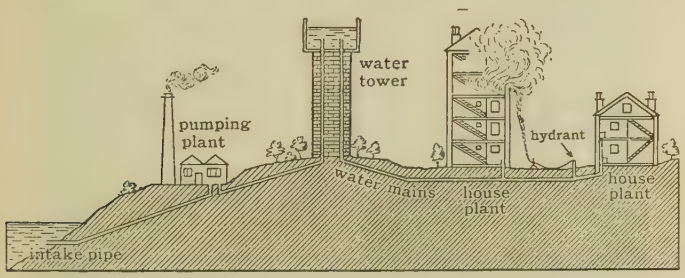


FIG. 145.—DIAGRAM ILLUSTRATING TOWN WATER SUPPLY.

made in the side and the water would not flow out of it. But water does flow through the hole, and if the hole is replaced by a pipe communicating with another empty tank, water will flow from one tank to the other until the water level is the same in both tanks. When this occurs the pressure in the pipe is balanced, that is, water on one side presses as much as that on the other side.

The flow of water from a higher level to a lower one is the result of unequal pressure and is the principle of town water supply. Water is pumped to a large reservoir situated on some hill or land at a higher level than that of the town, consequently all parts of the town receive water at reasonable pressure. (Fig. 145.) In many cases the reservoir is many miles distant and may consist of a natural or artificial lake. For example, the water supply of Liverpool is obtained from Lake Vyrnwy in

North Wales, a lake artificially produced by placing a dam 1180 feet long across the valley of the river Vyrnwy. (Fig. 146.) Manchester obtains its water from Thirlmere, a natural lake in Cumberland.

(*Topical Press.*)

FIG. 146.—SIDE VIEW OF THE DAM, LAKE VYRNWY.

In artesian wells (see Chapter IV), named from a district in France, advantage is taken of the fact that water in porous rocks in the hills is at a higher level than land where the well is situated.

The transmission of pressure through water is of great use in such appliances as the **hydraulic press,** in which a pressure on a small surface of water can produce an equal pressure per square inch on a large surface, thus giving a powerful advantage. Pressure exerted by a piston upon water in a small cylinder produces an equal pressure per square inch upon a much larger piston in a larger cylinder forming the bottom part of a press. It must not be imagined that something is obtained for nothing, however; the smaller piston must be moved through a corres-

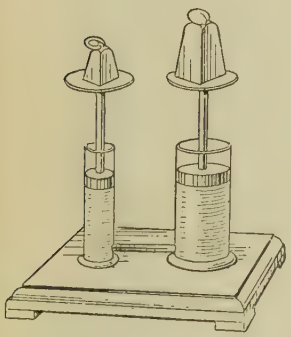


FIG. 147.

BY THE TRANSMISSION OF EQUAL PRESSURE PER SQUARE INCH, A SMALL WEIGHT BALANCES A LARGER WEIGHT.

(By courtesy of Messrs. Townson & Mercer.)

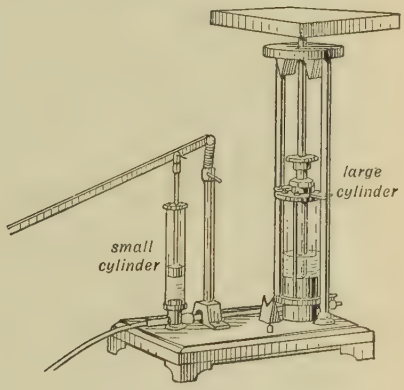


FIG. 148.—THE PRINCIPLE OF THE HYDRAULIC PRESS.

PRESSURE EXERTED BY A PISTON UPON WATER IN A SMALL CYLINDER PRODUCES AN EQUAL PRESSURE PER SQUARE INCH ON A LARGER PISTON.

(By courtesy of Messrs. Townson & Mercer.)

pondingly larger distance than the larger one. The case is one of mechanical advantage operated by hydraulic means. The principle of the press is also that of **hydraulic lifts** used in some hotels, etc. The cage of the lift corresponds to the larger piston of the press and is immediately above a long steel shaft supported by water in a very strong cylinder. Water under high pressure passes through a small pipe into this cylinder and the pressure causes the lift to rise. Taps control both the ascent and the descent.

A **hydraulic jack** employed for lifting very heavy bodies, such

as locomotives, is very similar to the press. A lever handle applies pressure to a small water column, and this is transmitted

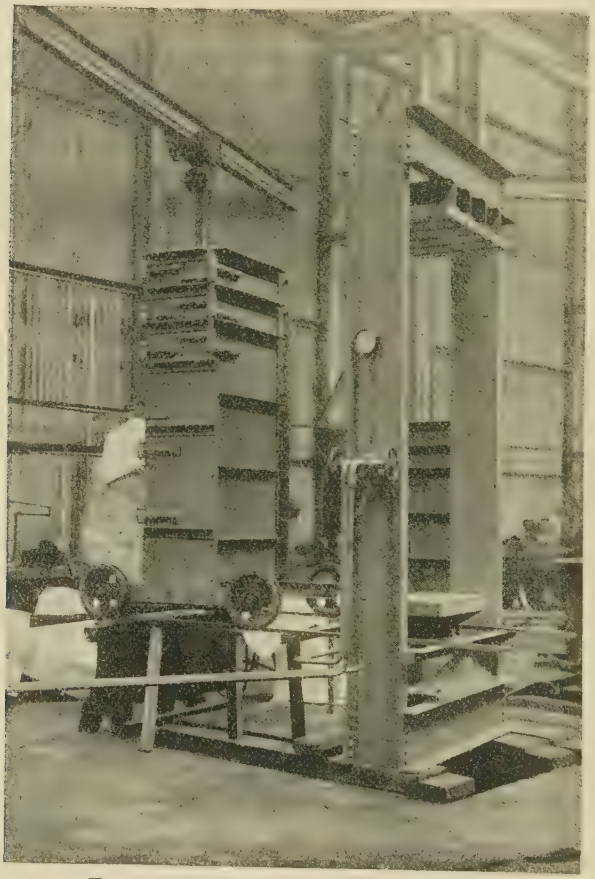


FIG. 149.—HYDRAULIC PACKING PRESS.
THE PRESS IS ON THE RIGHT, AND BALING CASES ARE SEEN ON THE LEFT.
(By courtesy of Hollings & Guest, Ltd.)

to a wider column, above which the end of a cylinder rises as the result of the pressure.

CHAPTER XVII

AIR PRESSURE IN RELATION TO DAILY LIFE

Air has weight, hence it exerts a pressure upon all objects it touches. The atmosphere extends upwards for many scores of miles, but the upper layers are extremely thin compared with the denser portions near the surface of the ground. The air, as other gases, can be compressed so that under a greater pressure a given weight of it can be forced to occupy a smaller space than it occupies under less pressure. The lower layers of the air have to support the weight of all the air above, hence the greater weight and density of the atmosphere just above the earth's surface. It must not be overlooked that if a pressure is exerted upon air, the air also resists and exerts a pressure against whatever is compressing it. This is noticeable in a bicycle pump ; if the connecting tube is closed with the finger, the handle of the pump is forced back by the air in attempting to regain its original volume. So far as volume is concerned, air is elastic (see Chapter XV).

The relation between the pressure upon a gas and the resulting volume is expressed by **Boyle's Law,** which states that *when the temperature remains constant the volume is inversely proportional to the pressure.* If the pressure is doubled, the volume becomes one half its original size, or if the pressure is halved, then the volume is doubled, and so on. **Robert Boyle** (1626-1691), a son of the Earl of Cork, devoted much of his time to the study of the physical properties of air, and was one of the original members of the ' Invisible College ' which later developed into the Royal Society in 1663.

Boyle's law can be verified by means of quite a simple apparatus consisting of a long glass tube of uniform width bent in the

shape of a U, but one side much longer than the other. (Fig. 150.) The smaller side is closed but the other is open so that mercury can be poured in as desired. The mercury is at first adjusted so that its level on both sides of the tube is the same, and air in the closed space at the upper part of the shorter tube is then subjected to the pressure of the external atmosphere at the time. Mercury on one side exactly balances that on the other side, hence the only pressure exerted on the enclosed air is that of the atmosphere, and as we shall see later, the average pressure of the air is equal to the weight of a column of mercury 30 inches high. Since the tube is of uniform width, the length *l* represents the volume of confined air, and if extra mercury is poured in, the pressure upon this air is increased, since the weight of a small column (*h*) of mercury above the level in the mercury in the smaller side of the tube must be added to that of the atmosphere. When sufficient mercury is added to give a column of about 30 inches higher than the level of the mercury in the shorter tube, the total pressure upon the enclosed air is about double the atmospheric pressure and the length *l*, hence the volume of enclosed air, is half its original size when the mercury was at the same level in both sides of the tube. The pressure has been doubled and the volume halved.

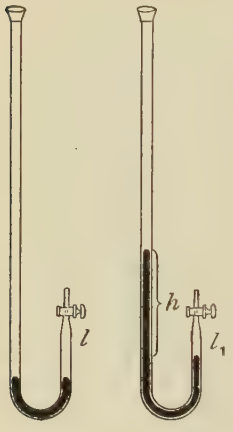


FIG. 150.

SIMPLE APPARATUS FOR THE VERIFICATION OF BOYLE'S LAW.

But it is not necessary to add so much mercury in order to prove Boyle's law, since, if the law is true, the product of the pressure multiplied by the volume gives a constant figure, as a consideration of the following cases shows: if the pressure (P) is 2, the volume (V) is $\frac{1}{2}$, then the product of P and V (PV) = 1; if P = 3, and V = $\frac{1}{3}$, then PV = 1; again if P = 4 and V = $\frac{1}{4}$, then PV = 1, and so on. By placing various quantities of mercury in the longer tube, measuring the difference in level *h*, and

adding this quantity to the air pressure as shown by a barometer at the time, the total pressure in each case is obtained. Then by measuring the respective lengths (l) of the enclosed air each time the mercury is added the volume is obtained and the value of PV can be found by calculation. Of course it is necessary to express h, l, and the atmospheric pressure in the same units, either inches or centimetres, the latter being used in laboratory work. Any gas obeys Boyle's law, provided the temperature remains constant and that it is not near the temperature at which it liquefies.

FIG. 151.—FORTIN'S BAROMETER.

HOW AIR PRESSURE IS MEASURED

The pressure exerted by air is of enormous importance in daily life since it largely determines the weather, influences the boiling of liquids, is related to the working of balloons and airships, and operates a great number of mechanical contrivances ranging from a simple pump to vacuum brakes on trains. Since the air pressure varies with conditions of temperature, humidity, and altitude above sea-level it is necessary to have some means of measuring it.

The apparatus commonly used is known as a **Fortin's barometer,** which consists of a glass tube of uniform bore and about one metre in length (Fig. 151). The upper end is closed but the lower end is open, and is placed below the level of mercury in a trough. At first the tube is completely filled with mercury and then inverted and the lower end placed in the trough, a finger preventing the escape of mercury until the tube is safely placed in position. On removal of the finger the mercury column drops until

its weight is exactly balanced by the external air pressure upon the mercury in the cistern. The arrangement is a kind of weighing machine in which a short heavy column of mercury balances a very long column of air which extends upwards as far as the furthest limit of the atmosphere. Note that the column of air is of *the same width or area of cross-section* as the mercury column which balances it, hence the bore of the barometer tube may be of any convenient size. As the air pressure varies, so the height of the barometer column varies correspondingly, and the air pressure is expressed in terms of the height of mercury above the level of that in the cistern, such height being measured in inches or millimetres, whichever is the more convenient.

FIG. 152.—A 'SIPHON' BAROMETER.

THE PRESSURE OF THE AIR AT *O* BALANCES THE COLUMN OF MERCURY ABOVE THE LEVEL OF *O* IN THE TUBE *A*. THE AIR COLUMN EXERTING A PRESSURE AT *O* IS OF THE SAME WIDTH AS THE MERCURY COLUMN.

Since the scale at the side of the mercury column of the barometer is fixed it is important that the mercury in the cistern shall be at the correct level, and when necessary it is adjusted by means of a screw underneath which raises or lowers the movable base of the cistern until the point of an ivory pin just touches the surface of the mercury. As the mercury barometer has seldom to measure pressures below that represented by 29 in. of mercury, a scale reading much below this is not necessary. A sliding vernier scale placed against the main scale enables one to read the barometer height accurately to a small fraction of an inch.

For use on board ship a modified form of barometer is mounted so that it remains vertical in spite of the rolling of the ship, and in place of the adjustable cistern is an enclosed iron case containing mercury at a fixed level.

The average or *normal atmospheric pressure at standard sea-level is equal to the weight of a column of mercury* 30 *inches or* 760 *millimetres in height*, and it has been accepted generally that the **average level of the tide at Liverpool shall be the standard sea-level,** or ordnance datum (O.D.) in mapping. As one ascends to higher altitudes above sea-level the air becomes less dense, and it has been proved that the barometer pressure usually decreases by one-tenth of an inch (about 2·5 millimetres) for every 90 feet of ascent.

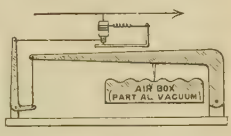


FIG. 153.—THE PRINCIPLE OF THE ANEROID BAROMETER.

THE SURFACES OF THE AIR BOX MOVE INWARDS OR OUTWARDS AS THE EXTERNAL ATMOSPHERIC PRESSURE VARIES.

This relation between altitude and air pressure affords a good means of finding the heights of mountains and levels reached during balloon ascents, but a form of barometer more portable than Fortin's must be used for such purposes. An **aneroid** barometer, as its name implies, is one in which no liquid is used, the air pressure being measured by its effect upon shallow circular metal boxes containing a partial vacuum (Fig. 153). If the air pressure increases, the surfaces of the boxes are pushed slightly inwards; if it decreases the box

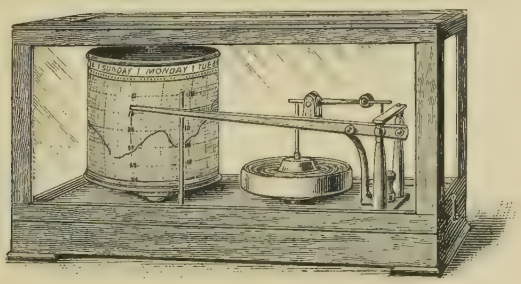


FIG. 154.—A BAROGRAPH.

surfaces move outwards. These movements are communicated to a pointer which moves over a graduated dial indicating air pressures. In larger forms of aneroid barometer several boxes are used so that the movements are increased, and in place of a pointer is a long lever with an attached pen which traces a line

on paper. The paper slowly rotates on a drum operated by clockwork, so that the line traced gives an accurate record of barometric pressures which have existed during a certain time, usually one week. A *self-recording* instrument of this type is called a **barograph,** since it gives a graph or drawing that represents the atmospheric pressure (Fig. 154).

Another reliable type of instrument, called a fisherman's aneroid barometer, is used on small vessels where a large ship's barometer containing mercury would be unsuitable.

AIR PRESSURE AND WEATHER

In most cases fine dry weather accompanies a relatively high pressure, and wet squally weather is associated with comparatively low air pressure, consequently the barometer is usually high with fine weather and low with wet weather, but though this is general, it is not always the case. When rain is likely, the air contains a considerable amount of water vapour, and such *damp air is lighter than dry air.* At first sight this appears strange since water is heavy, but the air contains water *vapour*, and this is lighter than air. Consider the matter in this way. If you have a cubic foot of dry air and then take away some particles of dry air, and in their places put particles of water vapour, you place a lighter substance where there was a heavier one, and the cubic foot of gas loses weight.

Air pressure is thus related to its **humidity,** or the relative amount of water vapour in it. The study of the weather or **meteorology** is a very complicated subject, and weather forecasts of any real value can be made only by experts supplied with sufficient data, but we can notice briefly one or two outstanding facts concerning air-pressure systems. Weather charts containing information regarding air pressures, temperature, winds, humidity, the state of the sky, etc., are issued daily by the **Meteorological Office.** Air pressures are shown on charts by continuous lines called **isobars**; each isobar is drawn to pass through all places with equal air pressure at the same time. The way in which these lines are related to one another is of great importance, since it gives an idea of the general air-pressure

arrangement existing at the time, and it is the type of pressure arrangement that normally determines the kind of weather experienced. Among the various kinds of pressure arrangements two types, **cyclones** and **anticyclones,** are of great importance and of common occurrence.

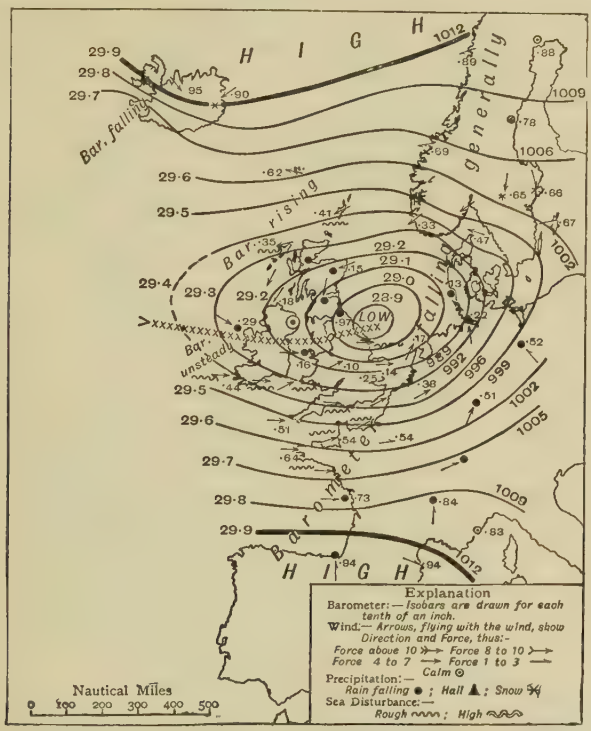


FIG. 155.—A WEATHER CHART ILLUSTRATING A CYCLONE SITUATED OVER THE BRITISH ISLES.

In a cyclone, which often extends over an area as large as Wales, the air pressures are arranged in roughly circular or oval form as represented by isobaric lines (Fig. 155). The centre of the system is a *low*-pressure area, the pressure increasing outwards in all directions. Since air flows from areas of high pressure to those of lower pressures, the winds of a cyclone blow

in towards the centre, their direction being spiral and anticlockwise on account of the earth's rotation. The air motion is somewhat similar to the spiral movement of the last portions of water escaping down the outflow pipe of a sink. The weather

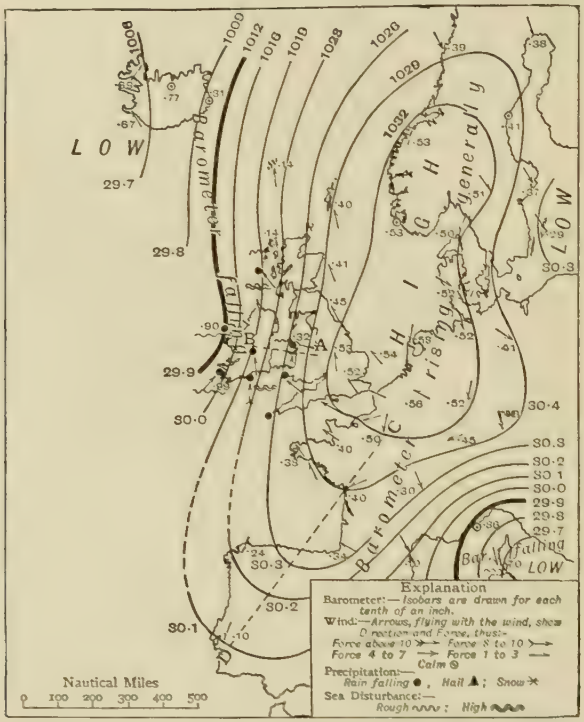


FIG. 156.—A WEATHER CHART SHOWING AN ANTICYCLONE OVER THE NORTH SEA.

accompanying a cyclone is wet, squally and cool in summer, but relatively warm and wet in winter.

In the latitudes of the British Isles these and other pressure arrangements move slowly across Europe from southwest towards the northeast, and take their weather with them, hence the weather Great Britain experiences to-day is frequently ex-

perienced by Scandinavia or the Netherlands in the course of a day or two.

The term cyclone is sometimes used to denote also **tropical revolving storms** or typhoons, in which the area embraced is relatively small, the centre of comparatively very low pressure, and the winds consequently very powerful. Such whirling systems move rapidly and cause great damage.

On modern weather charts air pressure is expressed in units called **millibars**, related to centimetres. A bar is equivalent to a pressure of 29·52 inches of mercury, and millibars are thousandths of a bar; 1015 *millibars are equivalent to the pressure of* 30 *inches of mercury.*

In an anticyclone the air pressure arrangement is the converse of that in a cyclone, the centre being an area of *high* pressure, and the pressure decreases outwards, consequently the winds blow spirally outwards from the centre in a clockwise direction (Fig. 156). An anticyclone frequently covers large areas, moves relatively slowly, and is associated with fine warm weather in summer and fine cold frosty weather in winter.

In all air pressure systems the force of winds depends upon the rate at which the air pressure changes. When the isobars on a chart are near together the change of pressure is rapid and the wind strong, but if the isobars are widely separated, the winds are less powerful. Just as altitude increases rapidly on a hill of steep gradient, so air pressure increases or decreases rapidly in areas where there is a steep **barometric gradient.**

AIR PRESSURE MECHANISMS

Air pressure capable of supporting a column of mercury 30 inches high presses upon everything with a weight of about 14·7 lb. per square inch. A page of this book has an area of about 30 square inches, so that the total weight of air pressing upon it is more than four hundredweight. Let us consider some practical consequences of this pressure. In the first place, why are we not pressed flat against the ground? If you blow up a football bladder it swells equally in all directions and assumes a spherical form. Should the air press forwards only, the football

would assume the shape of a sausage and not that of a sphere. Air presses equally in all directions, the downward pressure due to its weight being transmitted sideways and upwards as well. As we have seen in a previous chapter, this is characteristic of fluids. Our bodies are pressed equally in all directions, hence we remain as we are. Even the air in our lungs, when filled, exerts a pressure equal to that of the outside atmosphere, otherwise breathing would be impossible. A large travelling trunk possesses a lid having an area of about one square yard or 1296 square inches, and this means that the air normally exerts a pressure of no less than $8\frac{1}{2}$ tons on the lid, so that a powerful

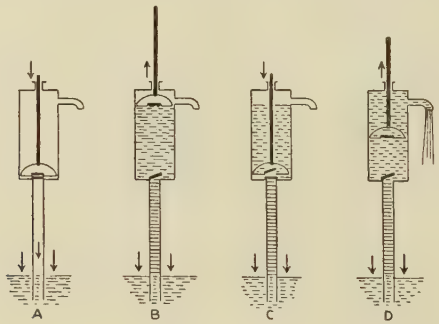


FIG. 157.—THE SIMPLE WATER PUMP.
THE SECTIONS REPRESENT THE CONSECUTIVE RESULTS OF THE FIRST TWO COMPLETE STROKES OF THE PISTON.

crane would be required to lift the lid if the air pressure were not also exerted sideways and upwards.

It is not surprising that such pressure is used for many domestic and commercial purposes. A barometer could be constructed to use water in place of mercury, but the tube would have to be at least 33 feet in height. Instruments of this kind have actually been tried, but they are inconvenient, and there are other reasons, such as evaporation, which make water unsuitable for barometric purposes. Nevertheless the average air pressure can support a column of water nearly 34 feet high, and this means that *theoretically* an ordinary 'suction' **pump** can raise water from a well provided that the distance through which the water

has to be raised is not greater than this. In actual practice, however, it is found that such pumps work efficiently only when the distance does not exceed 28 feet.

In an ordinary pump a piston is moved upwards in a cylinder and the outside air pressure presses water upwards to occupy the space which would contain a vacuum if the water did not follow the piston (Fig. 157). In common language the water is said to be ' sucked ' up, but in reality it is pushed up.

When the piston reaches the top and then commences a down-stroke, a valve at the bottom of the cylinder closes, but another valve in the piston itself opens and permits the water to pass to the space above. On the next up-stroke this water is ejected through the outlet pipe at the same time as more water is drawn into the cylinder.

Water is pumped from wells of greater depth by means of special apparatus which raises water by suction for the first 25 feet and then lifts a column of water for the rest of the way. In other words, the pump placed low down in the well is fitted with a long vertical delivery tube which enters the pump *below* the piston and is provided with a valve preventing water running back into the pump. An arrangement of this type which forces water in a tube to any desired height is known as a **force pump.**

In the earlier type of **fire engine** operated by steam, a continuous flow of water was ensured by the pressure of air in a vessel, otherwise the stream of water would have been spasmodic. The latest type of fire engine is operated by a petrol motor and specially designed pumps eject a continuous stream of water.

An apparatus simpler in construction than a pump, but by no means so simple to describe, is a bent tube called a **siphon.** This is used for the transference of liquid from one vessel to another, or for emptying a liquid from a container. The tube is first completely filled with the liquid and then one end is submerged in the containing vessel. The liquid then flows out at the further end of the tube until the vessel is empty or until the liquid comes to the same level in a second vessel as it is in the original container.

The action of a siphon may be understood by reference to Fig. 158. In the case of the U-tube to the left the pressure at

the top is balanced and there is no flow of liquid. In the case of the U-tube to the right the pressure at the top is not balanced. At the top of the left hand limb of the tube the pressure is that of the atmosphere less that due to 30 inches of mercury, *i.e.* the pressure is practically nil. But at the top of the right-hand limb the pressure equals that of the atmosphere less that of only twelve inches of mercury, hence there is a pressure forcing the liquid in the direction shown by arrows.

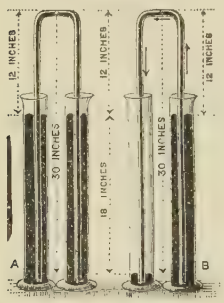


FIG. 158.—EXPLANATION OF A SIPHON.

THE PRESSURE AT THE TOP OF THE U TUBE TO THE LEFT IS BALANCED, BUT THAT AT THE TOP OF THE TUBE ON THE RIGHT IS NOT BALANCED.

Another practical application of air pressure is the **vacuum brake** used on railway trains (Fig. 159). This consists of a piston working in a cylinder and connected by a long train pipe to the engine pulling the train. A current of steam from the engine produces a vacuum in the train pipe and in the space below the piston. When air is permitted to enter the train pipe it also presses upon the underside of the piston but *not* upon the upper side, consequently the piston is forced upwards and the attached brakes are put on. After the brake has been applied, the engine again produces a vacuum by pumping air from the train pipe in order to take the brake off again.

The mode of producing the vacuum in the train pipe is interesting, as it illustrates the way in which a vacuum may be produced for some other purposes. A current of steam moving rapidly under pressure passes an aperture in the train pipe and, producing there reduced pressure, it pulls air from the pipe along with it. Such an arrangement is called an **ejector.**

A very high degree of vacuum such as that required to pump out air from certain forms of scientific apparatus, an X-ray tube for example, can be produced by the ejector principle, but mercury is used in place of steam. Mercury is allowed to fall through a tube, and as it does so, it pulls along with it bubbles of air obtained from another side tube connected to the vessel to be exhausted. More mercury can be added and the process con-

tinued. In this way an extraordinary degree of vacuum can be obtained, far more than that possible when an ordinary air pump is employed.

As a typical example of apparatus used in ordinary laboratory demonstrations, the **Hawksbee air pump** may be quoted. In this there are two cylinders containing pistons in such a way that as one piston is descending the other is ascending. The pistons communicate by a pipe with the glass or other vessel

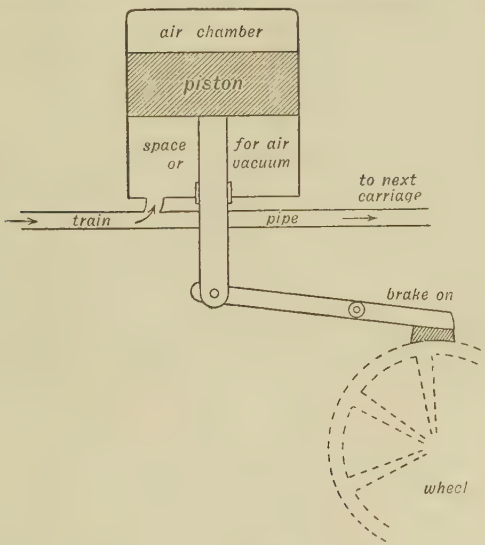


FIG. 159.—DIAGRAM REPRESENTING THE PRINCIPLE OF THE VACUUM BRAKE USED ON TRAINS.

from which the air is to be pumped. Each piston is fitted with a valve which allows air in the cylinder to be passed out on the down-stroke. An up-stroke of either piston draws air from the vessel into the corresponding cylinder and the process can be repeated several times. In working the apparatus a person uses his force against the pressure of the atmosphere on the upper sides of the pistons.

The ordinary atmospheric pressure is responsible for the correct working of railway signals in some methods of signalling.

Pipes connect the signals with the signal box, and since a signal is kept in the down or all clear position by air pressure in the pipes, a failure leaves the signal at the danger position.

The cases we have considered above afford examples of air employed at ordinary pressure, but many useful applications are operated by compressed air. As examples may be quoted compressed air drills, used in quarrying, street repairs, etc., the conveyance of telegrams along pneumatic tubes in post offices, and the **Westinghouse brake** employed on some trains. Such appliances require extra power and special machinery called air compressors, which force air to occupy a smaller volume and exert a greater pressure than is normally the case.

An **aeroplane** must be considered as a mechanism operated by the force of air pressing against the wings and certain movable parts. Just as a swimmer causes an additional upthrust in water by the movements of his limbs, so the aeroplane pulled through the air by its propeller causes the pressure on the wings to give a powerful upthrust, lifting and maintaining the machine in the air. As in the case of objects in water, an upthrust is equivalent to a loss in weight. The movable parts at the tail end of the aeroplane modify the pressure so that the machine ascends, descends, or turns sideways according to the will of the pilot.

CHAPTER XVIII

HEAT AND HOW IT IS MEASURED

In ordinary language, energy signifies capability or strength of action: in science, it is defined as the power of doing work. Heat does work when it changes water to steam which operates a locomotive; therefore heat is regarded as a form of energy. There is a definite relation between the amount of heat and the work performed, as we shall see in the next chapter.

One of the best known books of the famous physicist, **John Tyndall** (1820-1893), is entitled, *Heat, a Mode of Motion*; and it is certain that heat is a motion of the minute particles composing a substance—the hotter the substance is, the more rapidly the particles move. In a cool piece of iron the particles are already in motion, but if the iron be heated the movement of the particles is greatly increased.

The motion and energy of heat may be produced in a variety of ways, some mechanical, some electrical, others chemical, and so on. The heat produced when primitive man kindled a fire by rapidly rubbing pieces of wood together, and that developed when a rifle bullet is stopped suddenly by an armour plate, are examples of heat due to mechanical means. Friction between the parts of a machine is another, and in this case the heat produced represents a loss of effective energy, hence the necessity of oil and grease to lessen the friction. Whereas primitive man wanted the friction, the modern engineer does not. When an electric current flows along certain wires in an electric cooker, the energy of electricity is changed to heat because the wires oppose the current and become red hot in consequence. Opposition generally means the production of heat. In a coal fire and in an oil stove, energy of chemical action is being transformed to

heat and usually light as well. The carbon in coal and in oil combines so eagerly with oxygen in the air, or burns so readily, that much heat is developed by the chemical action. Slow chemical action, such as the rusting of iron, is not usually accompanied by any appreciable development of heat.

Light rays from the sun or other sources are accompanied by heat rays, and if these are focussed by a lens or ' burning glass ' to a small spot upon some thin paper, the concentrated heat rays cause the paper to burn. Attempts have been made to focus sufficient of the sun's rays to boil water, generate steam, and work an engine, but these ventures cannot compete successfully with other means of producing power.

The converse of these changes are of common occurrence and of great use. Heat can be made to do mechanical work, as in the locomotive already mentioned ; it can be changed into electricity, as in an apparatus called a **thermopile** ; it is often instrumental in promoting chemical changes between substances which will not react when they are relatively cool ; and in any of the common sources of light—candles, oil, electric lamps, and gas burners—considerable heat is necessary for the substance to become luminous.

One form of energy can be converted to another, and though naturally no energy is really destroyed, in practical applications there is always some loss when a transformation of energy is accomplished. If it were not so, engines would have an efficiency of 100 per cent., but this is far from being the case. A great deal of energy is dissipated, or escapes being harnessed for practical purposes, and such dissipated energy is mostly in the form of heat. That produced by friction in parts of machinery is an example.

SOME CONSEQUENCES OF EXPANSION AND CONTRACTION IN SOLIDS AND LIQUIDS

Heat being a mode of motion of the minute particles composing a substance, it follows that when a substance becomes hotter the particles require more room for their increased motion. The very obvious result of this is the expansion of the heated material ;

the more heat supplied, and the higher the temperature rises, the more the material expands.

In the case of most substances a rise in temperature leads to expansion and if the heating process be continued sufficiently, the particles will obtain more and more room for their movements and the substance if solid will liquefy, and if liquid will become gaseous. The substance changes its physical state; but more will be said about this later. Most substances expand by a definite amount for every degree the temperature is raised, and

Fig. 160.—The Forth Bridge.

in the case of solids and liquids the amount that one substance expands for one degree is not usually the same as that for a different substance. Thus, for a given rise in temperature, a piece of brass expands a little more than a piece of copper of the same size, and much more than a piece of steel of the same initial volume. The actual increase of size for each degree of temperature is very small. A steel rod one yard in length at 0° Centigrade would be 1·000011 yards at 1° C., and 1·0011 yards at 100° C. The quantity 0·000011 is called the **coefficient of linear expansion** of steel, since it represents the fraction of the original length at 0° C. that a rod of steel will expand for every degree Centigrade its temperature is raised. The coefficient of surface expansion is about double, and that of volume expansion is roughly three times the linear coefficient.

These quantities are quite small, but nevertheless of some

practical importance. A sufficiently large space must be left between two portions of a railway line to allow for expansion in hot weather, otherwise the rail would be badly buckled. Steel bridges are so constructed that allowance is made for changes in temperature at different seasons. Usually the ends of the bridge rest on rollers, but in very large structures, such as the

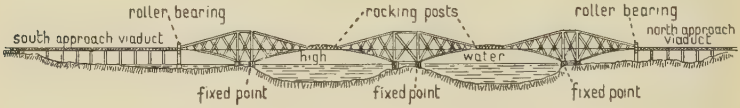


FIG. 161.—SECTION OF THE FORTH BRIDGE.
SHOWING POSITIONS OF ROLLER BEARINGS AND ROCKING POSTS.

Forth Bridge in Scotland, in addition to rollers at the ends, the main portions of the bridge, the cantilevers, are connected by girders having 'rocking posts' which assist in adaptation to temperature (Figs. 160 and 161). The Forth Bridge is 5349·5 feet long, and this means that on a warm summer day the bridge is nearly one foot longer than it is on a cold winter day.

Iron pipes meant to convey hot water or steam should be fitted with some device permitting expansion and contraction.

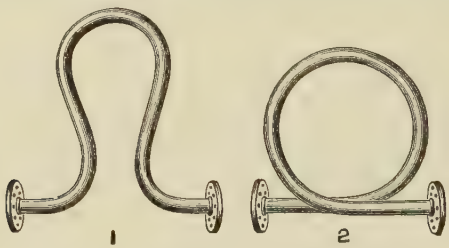


FIG. 162.—EXPANSION BENDS.
THESE INSERTED BETWEEN LENGTHS OF PIPING PERMIT THE PIPES TO EXPAND AND CONTRACT WITH CHANGES OF TEMPERATURE.

Changes in length are permitted by the use of expansion joints or by expansion bends (Fig. 162). The former consists of a gap between two portions of piping, with a surrounding collar tube above the gap and the ends of the piping, and the latter consists of curved pieces of tubing which act as springs.

Changes in temperature also affect the length of a pendulum in a clock or the diameter of a balance wheel in a watch. A clock keeps correct time if its pendulum retains its proper length, and a watch marks time properly if the diameter of its balance wheel remains the correct size.

Various devices have been employed to compensate for expansion and contraction in clock mechanisms. In **Graham's mercurial pendulum** (Fig. 163), mercury in a vessel or vessels expands upwards as the main rod of the pendulum expands downwards, and if the mercury column is of the correct length, the two effects are nicely balanced. **Harrison's gridiron** pendulum consists of several steel rods alternating with others composed of brass, and so arranged that as the steel rods expand downwards, those of brass expand upwards to the same extent. Consequently the centre of the bob is neither lowered nor raised, and this is the thing which really matters as far as time keeping is concerned. There is bound to be an extra steel rod, the middle one supporting the bob, hence the use of the more expansive brass for the other set of rods.

Fig. 163. Graham's Mercurial Pendulum.

The invention by the French physicist, M. Guillaume, of an alloy of steel and nickel named **invar**, has rendered the use of these rather cumbrous modes of compensation unnecessary. This alloy expands or contracts by such small amounts that its length is for practical purposes invariable for ordinary changes of temperature due to the weather, hence the name "invar," an abbreviation of invariable. Its coefficient of linear expansion is only 0·0000009.

The balance wheel of a watch is caused to oscillate by a fine steel hair-spring, and if by reason of a rise in temperature the wheel becomes bigger, its motion is slower and the watch loses time. Conversely, by a fall of temperature it may move too quickly. In order to prevent such temperature effects the balance wheel is composed of two metals, one more expansible

being outside the other. Three arms or spokes support the circumference, and there is a gap in the circumference near each spoke. When the spokes expand outwards the more expansible metal of the circumference causes the further end of each arc to curl slightly inwards, so that the average diameter of the wheel is kept constant.

The examples described show that expansion is generally a nuisance, but this is not always the case. Old buildings, the walls of which exhibit a tendency to fall outwards, can be strengthened by long iron bars extending from one wall to that on the other side and fastened externally by cross-bars and nuts screwed up tightly while the bar is hot. Then the enormous force of contraction on cooling pulls the walls slightly together. The iron rim of a cart-wheel is put on hot, so that it fits tightly when it is cold.

This is the general rule, but there are one or two exceptions, the most notable being the contraction of water when heated so that the temperature rises from 0° Centigrade to 4° Centigrade. The reverse also holds good ; that is to say, water expands when cooled from 4° to 0° Centigrade. Above 4° Centigrade water expands on being heated. (The Centigrade scale of temperature is that mostly used in scientific work, and with other scales it is described below.) From what has been said about the expansion and contraction of water, it is clear that *water is at its maximum density at* 4° *C.* One result of this is that the gramme—the unit of weight in the metric system—is accurately the weight of one cubic centimetre of pure water only when the water is at this temperature. The water at the bottom of a pond in winter may be one or two degrees above 0° Centigrade, though the surface layers are frozen, a fortunate circumstance for living creatures inhabiting the pond. Other substances which expand slightly on solidification are cast iron and type metal (Chapter XL.).

THERMOMETERS AND THE INDICATION OF TEMPERATURE

Temperature is the degree of hotness of a body, and heat passes from a hotter body having a higher temperature to a cooler body having a lower temperature.

In scientific work where exact measurements of temperature are necessary, thermometers are of much use, and in daily life these instruments are employed in a variety of ways. The more modern types of electric ovens are fitted with thermometers specially designed to register high temperatures ; others of more simple design are employed in public buildings, swimming baths, hydropathic establishments, and in horticultural work. In medical practice a special clinical thermometer is of frequent use, since a rise in blood temperature of only two or three degrees means that a person is suffering from one of the many forms of fever (Fig. 164).

The action of a thermometer is based upon the fact that a liquid expands by a definite fraction of its original volume for every degree through which the temperature is raised. The

Fig. 164.—A Clinical Thermometer used by Physicians.

liquid generally employed is mercury, the coefficient of volume expansion of which is 0·000182. Thus a cubic centimetre of mercury at 0° C., becomes 1·000182 c.c. at 1° C., and 1·0182 c.c. at 100° C. These figures represent the **real expansion** of mercury after allowance has been made for the expansion of the vessel in which the liquid is contained. The visible expansion of mercury in a thermometer is called the **apparent expansion,** that of the containing vessel making it slightly less than the real expansion. But since we require in everyday life an instrument which will indicate changes in temperature and not coefficients of expansion, an ordinary thermometer which shows a regular increase in length of a thread of mercury corresponding to a steady rise in temperature answers our purpose very well.

Mercury in a glass bulb expands on being heated, and rises in a tube of very narrow bore compared with the size of the bulb, and often crescent-shaped in section, consequently a small expansion of the mercury produces a visible effect in the narrow tube.

When a thermometer is being made, air is expelled from the bulb by heat and then sufficient mercury is ' sucked ' in to fill

the bulb and a small portion of the tube. In order to make a scale of temperature, at least two positions of the mercury corresponding to two widely different temperatures are required. The lower *fixed* point, as it is called, is usually obtained by placing the bulb in melting ice placed in a funnel so that water can be drained away (Fig. 165). When the position of the mercury in the bore becomes steady, a mark is made upon the glass and that point is called 0° on the **Centigrade** scale, invented by **Celsius** in 1742, and on the scale of **Réamur,** also used in Continental Europe. But on the **Fahrenheit** scale, used domestically in the British Isles, this point is called 32°, Fahrenheit obtaining his zero position by using a mixture of salt and ice. For the upper fixed point all three scales now use the position of the mercury when the thermometer is placed in the steam being produced from water boiling at normal atmospheric pressure.

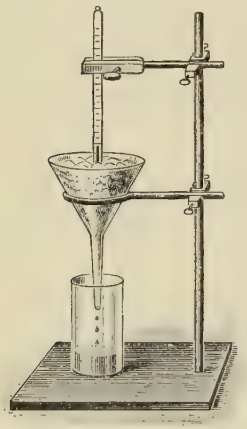


FIG. 165.
THE METHOD EMPLOYED TO FIND THE LOWER FIXED POINT OF A THERMOMETER.

This upper point is called 100° Centigrade, 80° Réamur, or 212° Fahrenheit as the case may be. When the upper fixed point has been found, the thermometer tube is sealed by heat and the length of tubing between the fixed points is divided into an equal number of subdivisions or degrees, the actual number of which depends upon the scale chosen. It is clear that

$$100^\circ \text{ C.} = 80^\circ \text{ R.} = 180^\circ \text{ F.},$$

the 32° below the temperature of melting ice being ignored in the case of Fahrenheit (Fig. 166).

A reading on one scale can be converted to the equivalent reading on either of the other scales without difficulty. Thus, to convert 40°C. to the equivalent reading on each of the other scales :

$$40^\circ \text{ C.} = (40 \times \tfrac{80}{100}) = 32^\circ \text{ Réamur,}$$

and

$$40^\circ \text{ C.} = (40 \times \tfrac{180}{100}) + 32 = 104^\circ \text{ Fahrenheit.}$$

Note that in the latter case the 32° below the Centigrade zero must be added. Consider the reverse of this last example. What is the Centigrade reading corresponding to 104° F.? The 32° below Centigrade zero must first be subtracted, leaving 72°.

$$104^\circ \text{ F.} = (104 - 32) \times \tfrac{5}{9} = (72 \times \tfrac{5}{9}) = 40^\circ \text{ C.}$$

Examples of instruments designed for special purposes are the **clinical** thermometer used by physicians, and the self-registering **maximum** and **minimum** thermometers employed by gardeners and by meteorologists for obtaining temperatures of the air for weather reports.

In the clinical thermometer there is a narrow constriction which allows the mercury to pass forwards under the pressure of expansion, but prevents it from going back again, hence the temperature can be read after the instrument has been removed from the patient. The mercury is brought back to its original position by jerking the thermometer. The scale indicates degrees extending from 95° F. to 110° F., the normal blood temperature being 98·4° F. Few people survive after reaching a temperature of 106° F., and general weakness may be accompanied by a temperature slightly below normal.

The clinical thermometer is a variety of maximum thermometer, but that used by gardeners and weather experts is of a larger and more robust type. A small steel index in the bore of the tube is pushed along by the mercury as it expands, and it is obvious that the nearer end of

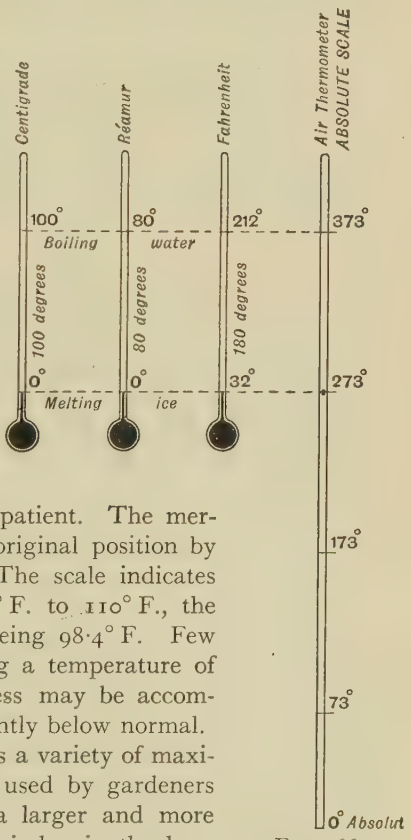


Fig. 166. Different Thermometric Scales.

this index will be left at the highest degree mark reached by the mercury. A small magnet can be used to draw the index back again when desired. In a **minimum thermometer** alcohol is used in place of mercury, and a small index is placed in the alcohol. The liquid flows past the index on expansion but drags the index back with it on contraction, hence the index registers the lowest temperature reached during the night or other period of time.

Instruments used in connection with meteorological work are placed in white screens composed of laths of wood resembling venetian blinds. This box-like arrangement is known as a **Stevenson's screen** and allows air to circulate freely through it, but prevents direct sunshine from affecting the instruments, since shade temperatures only are required.

EXPANSION OF GASES

When the same initial volumes are heated, it is found that alcohol expands much more than mercury for the same increase of temperature ; thus different liquids have different coefficients of expansion, though sometimes two or more liquids may approach very closely in this respect. The coefficients of water and mercury are almost the same. Similarly with solids, the coefficients of expansion differ, but *gases all have the same coefficient of expansion* ; they all expand by the same amount for a given rise of temperature, provided the pressure on them remains constant, and that they are not near the temperature at which they liquefy.

The relation between the volume and temperature of a gas is expressed by **Charles's Law,** which states that *at constant pressure any gas expands* $\frac{1}{273}$ *of its volume at* 0° *C. for every degree Centigrade the temperature is raised.* Thus, if the volume at 0° C. is 273 c.c., at 1° C. it will be 274 c.c., and at 100° C. the volume will be 373 c.c. Similarly going down the scale, at – 1° C. the volume will be 272 c.c., at – 100° C. it will be 173 c.c., and so on. What will it be at – 273° C. ? Theoretically there will be no volume at all, but as a matter of fact all known gases liquefy before they reach this very low temperature. There is another

scale of temperature known as the **Absolute scale,** and on this the zero or 0° Absolute is equal to −273° C. Absolute zero really means no temperature at all, but even in the production of very low temperature necessary for the liquefaction of air (see Chapter XXXIII), we have not quite reached the bottom of the scale.

What happens if a volume of gas enclosed in a strong metal vessel of definite size is heated strongly ? The gas cannot expand, but its pressure increases as the temperature rises, and this increase in pressure at constant volume also conforms to Charles's Law. *For every degree Centigrade (or Absolute) the pressure increases by* $\frac{1}{273}$ *of the pressure at* 0° *C. provided the volume is kept constant.* The enormous increase of pressure at constant volume is used in steam engines of all kinds, super-heated high pressure steam being taken by strong tubes to pistons or turbines as the case may be.

TEMPERATURE AND QUANTITY OF HEAT

Temperature is one thing, quantity of heat is another. Heat quantity can be measured in definite units, and the amount of heat in a gallon of water at 15° C. is much greater than that in a 1 lb. iron weight at 50° C. But if we place the iron weight in the gallon of water, heat passes from the hotter weight to the cooler water until both are at the same temperature. Evidently the terms hotter and cooler refer to temperature conditions, and temperature in heat corresponds to water level in hydrostatics. If it has the chance, heat will always pass from a substance having a higher temperature to one at a lower temperature irrespective of the actual quantities of heat in each substance.

The mercury in a thermometer expands because it receives heat from a substance having a higher temperature than it has itself, and the transference of heat and consequent expansion of the mercury continue until the temperature of the thermometer is the same as that of the substance. Thermometers measure temperature, not quantity of heat. When we wish to measure heat quantity we use a **calorimeter,** which is simply a small cylindrical copper vessel for holding water (Fig. 185). The scientific

unit of heat quantity is called a **calorie** and is that amount of heat required to raise the temperature of one gramme of pure water 1° C. Thus the heat required to raise the temperature of one gramme of water 100° is 100 calories, and to raise 100 grammes 1° also requires 100 calories. Water loses similar quantities of heat as it cools ; for example, 100 grammes of water in cooling from 100° to 0° give out 10,000 calories.

It is quite easy to calculate the final temperature of the mixture when a certain quantity of hot water is mixed with another quantity of cold water. Find the final temperature when 60 gm. of water at 20° C. are mixed with 30 gm. of water at 80° C. Now if x represents the final temperature, it is clear that the 60 gm. are raised through $(x - 20)$ degrees, and the 30 gm. of hot water lose $(80 - x)$ degrees. Equating heat gained against heat lost, we have :

Heat gained.	Heat lost.
$60(x - 20)$	$= 30(80 - x)$
$60x - 1200$	$= 2400 - 30x$
$90x$	$= 3600$
x	$= 40.$

The final temperature is 40° C. The only apparatus required for this is a calorimeter, thermometer, and of course a balance for weighing the water. The calorimeter will take a little of the heat so that the practical result will not quite agree with the theoretical result given above.

Now, if 30 gm. of iron at 80° C. were used in place of the hot water, the result would not be the same ; the temperature would be much lower than 40° C., in fact it would be about 23° C. This is because the same weight of iron in cooling through the same number of degrees gives out far less heat than water does. Iron also requires far less heat than water does to raise its temperature the same amount when equal weights are used. These facts are stated simply by saying that *water has a much greater capacity for heat than iron has* ; in fact, water has a greater capacity for heat than nearly all other substances. At constant pressure the gas hydrogen has a capacity greater than that of water. *The ratio of the capacity for heat of a*

substance to that of an equal weight of water is called the **Specific Heat** *of the substance.* If the specific heat of water be taken as unity, then that of most other substances is represented by fractions.

The specific heat of iron is 0·114, and this statement means that one gramme of iron in cooling 1° C. loses only 0·114 of a calorie. Now we are in a position to see why the final temperature in the problem above is about 23° C. when 30 gm. of iron is used in place of hot water. As before, x represents the final temperature. In this case heat gained = heat lost.

Heat gained. Heat lost

$$60(x-20) = 30(80-x) \times 0{\cdot}114$$
$$60x - 1200 = (2400 - 30x) \times 0{\cdot}114$$
$$60x - 1200 = 273{\cdot}6 - 3{\cdot}42x$$
$$63{\cdot}42x = 1473{\cdot}6$$
$$x = 23{\cdot}2^\circ \text{ C.}$$

Other problems on specific heat may be worked in this way; the specific heat of a substance can be found if all the other quantities are known.

The list below gives the specific heats of some common substances.

Water	1	Ice	0·471
Alcohol	0·62	Aluminium	0·214
Turpentine	0·42	Iron	0·114
Mercury	0·033	Copper	0·095

Differences in specific heat account for the fact that some substances are more easily heated than others; for example, a pint of milk boils more quickly than a pint of water, oils are quickly warmed, and a copper kettle is slightly better than one composed of aluminium. But the greatest practical result is that depending upon the relative capacities for heat of water and land. The sea takes very much longer to warm up in summer than land does, hence at this time of the year the sea keeps the land near it cooler than it would be if it were part of a continental mass. In winter the sea loses its heat slowly and so causes the adjacent land to be warmer than it would be if far removed from the ocean.

For these reasons maritime climates are more equable, that is, less subject to extreme temperatures, than continental climates.

Large tropical masses of land near the ocean are subject to periodic winds called **monsoons** which depend upon the relative amount of heat in water and land. In the hotter season the temperature of the land rises rapidly and the air above it ascends vertically, and cooler rain-bearing winds blow from the sea to

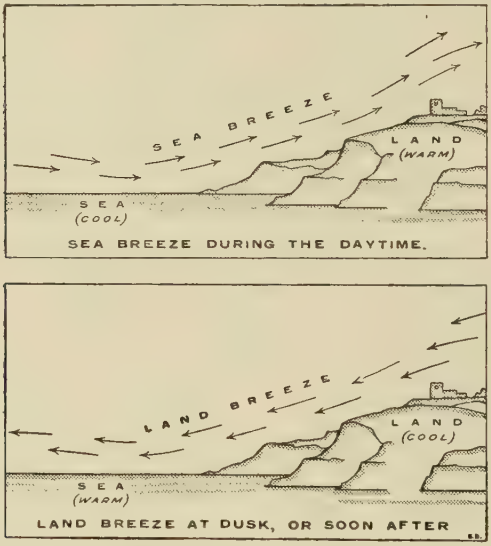


FIG. 167.—LAND AND SEA BREEZES.
THE TERMS WARM AND COOL INDICATE *relative* CONDITIONS.

the land. This continues for some months and then conditions are reversed; the sea being relatively warm, the winds then blow from the land to the sea, and this is the period of smaller rainfall. The northern part of Australia and some other regions are subject to monsoons of this kind. Somewhat similar effects, but on a smaller scale and of daily occurrence, occur at most coastal places and are called land and sea breezes (Fig. 167). During the day the warmer air above the land ascends and the cooler air

blows in from the sea, but at dusk conditions are reversed, and a land breeze sets in.

The south-west monsoon which brings rain to India in the spring is not, however, due to the heated land of India, as is usually stated, but to moist air from the South Indian Ocean being forced upwards when it reaches high mountain walls, and thus cooled by expansion and elevation, with the result that its moisture is precipitated.

The units of heat we have so far considered are calories, which are of scientific importance because they are related to grammes, the units of weight. In physiology **large calories**, each equivalent to 1000 ordinary calories, are employed (see Chapter XI). In connection with heat engineering, the **British Thermal Unit** (B.Th.U.) is employed, this unit being the quantity of heat required to raise the temperature of 1 lb. of water 1° F. Suppose a saucepan holds 5 lb. of water, and it is required to heat this water from 60° F. to 212° F., or the boiling point, how many British thermal units are required?

The units necessary are $5 \times 152 = 760$, if we ignore the heat taken by the saucepan. If we include this, and the saucepan weighs another 5 lb., then, since the specific heat of iron is 0·114, the extra B.Th. units required are $5 \times 0{\cdot}114 \times 152 = 86{\cdot}64$, making a total of 848·64.

Since coal gas is now used mainly for heating, its quality depends upon how much heat it produces per cubic foot. The unit employed in connection with gas supply is called a **therm** and is equal to 100,000 B.Th.U. If the gas is of the proper quality, 222 cubic feet of it will, in burning, yield one therm. Though the quality is determined by the fraction of a therm per cubic foot, the consumer is charged for the number of cubic feet consumed.

CHAPTER XIX

THE RELATION BETWEEN HEAT AND WORK

When the temperature of a bar of iron is raised its molecules require more room for increased vibration, and the energy necessary for such increased motion and consequent expansion is supplied in the form of heat In causing the expansion of the metal bar heat performs work. The matter can be considered in the converse way; forms of mechanical or other work may be performed with the production of heat; and it was by approaching the problem along these lines that **J. P. Joule** in the year 1849 determined the relation between the amount of work performed and the quantity of heat produced. A definite amount of work is always equivalent to a certain quantity of heat. Dr. Joule was a Manchester brewer by profession and has given us a fine example of successful scientific achievement attained by a business man in his spare time. In his experiments, the actual form of work employed by Joule was that performed by falling weights, the amount of mechanical work being calculated by the size of the weights and the distances through which they fell.

As explained in Chapter XIV, the amount of work is expressed in foot-pounds. In Joule's experiment the energy of the falling weights was communicated by means of wheels and cords to a spindle which rotated as the weights fell (Fig. 168). Attached to this spindle was a set of vanes rotating in water contained in a closed vessel. Joule performed a large number of experiments, and in some cases used mercury in a suitable form of apparatus, but the results always worked out the same. He showed that *in order to raise the temperature of* 1 *lb. of water* 1° *Fahrenheit*, 772 *foot-pounds of mechanical work had to be done.* In more recent times the experiment has been performed with better

apparatus and the result gives 778 foot-pounds as equivalent to the amount of heat required to raise a pound of water 1° F. (one British thermal unit). The relation: 778 foot-pounds of work = one water-pound-degree Fahrenheit is known as **Joule's equivalent,** and is represented by the symbol **J.**

Of course equivalent results are obtained when other units of weight and temperature are employed. In scientific work, **C.G.S.** (centimetre, gramme, second) units are often used, and in this case Joule's equivalent gives the work done by 427 gramme metres per water-gramme-degree Centigrade. Whether the amount of heat developed is expressed in British thermal

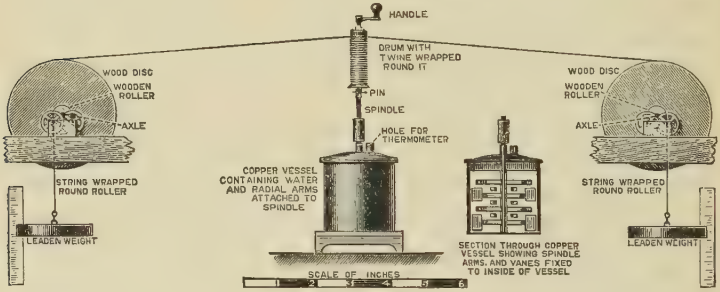

HANDLE
DRUM WITH TWINE WRAPPED ROUND IT
WOOD DISC
WOODEN ROLLER
AXLE
PIN
SPINDLE
HOLE FOR THERMOMETER
STRING WRAPPED ROUND ROLLER
LEADEN WEIGHT
COPPER VESSEL CONTAINING WATER AND RADIAL ARMS ATTACHED TO SPINDLE
SECTION THROUGH COPPER VESSEL SHOWING SPINDLE ARMS, AND VANES FIXED TO INSIDE OF VESSEL
SCALE OF INCHES
1 2 3 4 5 6

FIG. 168.—THE APPARATUS USED BY JOULE TO DETERMINE THE MECHANICAL EQUIVALENT OF HEAT.

units or calories, the actual relation between work done and heat produced remains the same. The great value of Joule's work lies in its proving that heat is a form of energy and not a kind of material substance as was generally believed prior to 1840, when it was thought that an object was hot because it contained a substance called *caloric*.

STEAM ENGINES AND TURBINES

Heat applied to water does work in raising the temperature, in converting water to steam, and in maintaining the steam at a high temperature and pressure. Because work has been done, the steam in its turn can be made to do useful work by means of its pressure when confined in a closed container.

Steam engines are either stationary and used for driving other kinds of machinery or they are locomotives employed for pulling trains, furniture vans, etc. Locomotives used on roadways are generally termed traction engines.

Everyone is familiar with the chief parts of a steam engine. There is a boiler for the generation of steam which moves a piston in a cylinder, and the movements of the piston cause a wheel to rotate.

The mode of working of a typical stationary engine can be understood by reference to the accompanying illustration (Fig. 169). The **piston** in a cylinder is pushed forwards and backwards by steam,

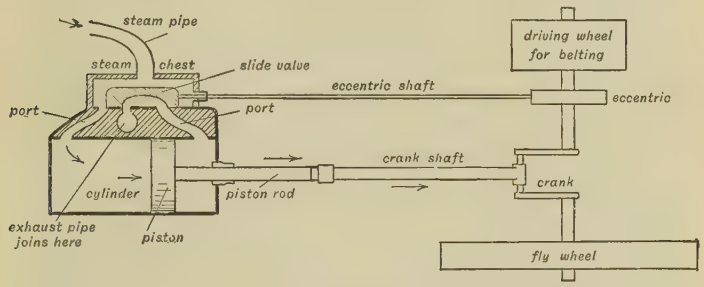


FIG. 169.—PLAN SHOWING THE CHIEF PARTS OF A STEAM ENGINE EMPLOYED FOR DRIVING MACHINERY IN FACTORIES, ETC.

and its movements are communicated to the driving wheel by means of a **piston rod, crank shaft,** and **crank.** A large **fly-wheel** keeps the motion steady. Admission of steam to the cylinder takes place through a steam chest having two separate openings or **ports,** one at the back of the cylinder, the other at the front. A sliding mechanism known as a **slide valve** covers the ports alternately, so that the steam is admitted to the back of the cylinder and pushes the piston forwards and then to the front of the cylinder and pushes the piston backwards. The slide valve itself is operated by a separate shaft and a ring which slides round an **eccentric disc** placed on the shaft of the driving wheel. The eccentric and the ring together form a timing device.

As the piston moves forwards, steam remaining in the front part of the cylinder is discharged through an **exhaust** pipe;

similarly, as the piston moves backwards steam in the back portion of the cylinder escapes through the exhaust pipe. In order that the cylinder shall be as steam-tight as possible, the piston rod passes through an aperture fitted with an arrangement called a **gland** and **stuffing-box**, the stuffing being composed of asbestos.

In a locomotive the parts and mode of working are similar, but there are two pistons, one on either side, and these are connected by crank shafts to the large driving wheels. The more bulky portion of the locomotive consists of the boiler having a large fire box at the rear end and a smoke box at the front end.

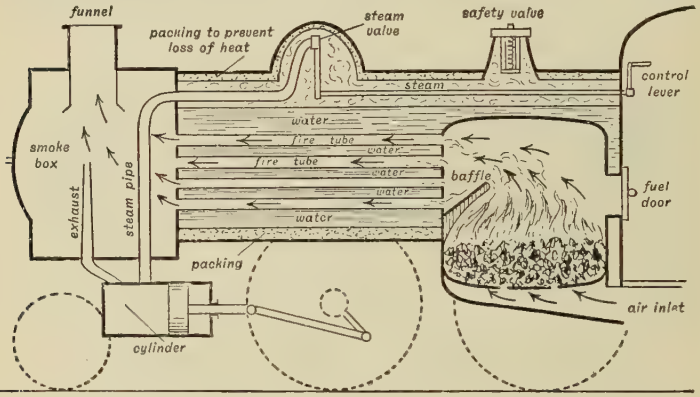


FIG. 170.—VERTICAL SECTION THROUGH THE BOILER OF A LOCOMOTIVE.

The boiler itself is of the ' fire tube ' kind, composed of a large number of tubes along which pass the heated gases from furnaces, and the water is in contact with these tubes (Fig. 170). The heated gases are passed into the smoke box and discharged through the chimney. The puffing of a locomotive is due to steam passed from the exhaust into the chimney, and this causes a strong draught of air to pass from the furnace through the tubes. Pipes communicating with a large steam dome above the boiler deliver steam to the cylinders, and a safety valve prevents the pressure from becoming too great.

The modern steam engine is the result of many successive developments and experiments. Prior to the time of **James**

Watt, such steam engines as existed were employed for pumping water from mines, and were appliances in which condensing steam formed a vacuum so that the air pressure did the actual work. Hence the first of these, known as **Savery's pumping**

FIG. 171.—A PULSOMETER
USED FOR PUMPING DIRTY WATER FROM OLD CLAY PITS, ETC.

engine, and a later type invented by **Newcomen**, were atmospheric engines. A modern steam pump which may be regarded as a type based upon the principle of Savery's machine is the **pulsometer** (Fig. 171). Watt's earlier engine (1769) used steam in place

of the atmosphere to work a piston, and later, in 1782, he invented the first engine in which steam pressure acted upon both sides of the piston. The engines designed by Watt worked at pressures little more than that of the atmosphere. **Trevethick,** a Cornishman, being the first to use high pressure steam at the beginning of the nineteenth century.

Trevethick invented the first locomotive, which ran on a railway at Merthyr Tydfil in South Wales in 1802, but it was not until 1829, when the **Stephensons** constructed the *Rocket*, that the

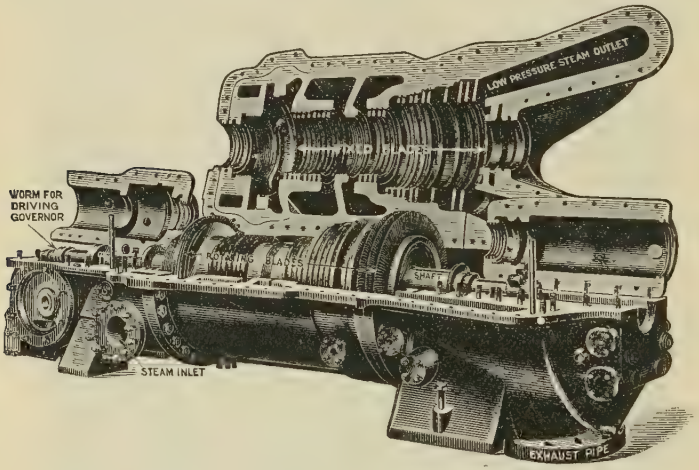


FIG. 172.—A PARSONS' STEAM TURBINE.
THE UPPER PART OF THE CASING LIFTED TO SHOW THE ARRANGEMENT OF ROTATING AND FIXED BLADES.

future of steam railways became assured. The first steamboat, driven by a paddle at the stern, was invented by **William Symington** in 1802, but in 1812 **Bell** constructed the *Comet*, having paddles at the sides.

The most important development in the use of steam power in modern times is the use of the steam turbine, in which high-pressure steam is forced against the curved blades forming an enclosed wheel, or rather sets of wheels.

In the **de Laval** type of turbine steam is directed by nozzles against the blades, and the impact pushes them forward at very

great speed. Such speed is inconveniently great, hence in some forms of steam turbine the rate is reduced by means of gearing. The widely used type of machine invented by **Sir Charles Parsons** makes use of a different principle, the steam *reacting* with curved blades so that they rotate in the other direction, resembling, in this respect, the backward rotation of a lawn sprinkler. Rings of rotating blades alternate with blades fixed to an outer casing, and a distinctive feature is the gradual increase of size of the rings proceeding from the end where the steam enters. This arrangement distributes the fall of steam pressure in such a way that the speed of the shaft is not too great though the power is there all the same.

INTERNAL COMBUSTION ENGINES

In steam engines the energy is derived from combustion of fuel taking place outside of the cylinder, but in petrol engines used for motor cycles, cars, and boats, and in gas engines commonly employed in factories, the combustion of the gaseous fuel takes place within the cylinder itself, hence such machines are operated by *internal combustion.* In all these cases an explosive mixture of air and gas is formed at the head of the cylinder and then fired by electrical or other means just as the piston is starting on a forward stroke. As in steam engines, the energy is the result of chemical work and heat. Since petrol, or spirit obtained from the distillation of petroleum, is so widely used as fuel, the engine of a motor cycle may be taken as an illustration of the way in which internal combustion engines work (Fig. 173).

As in most other engines, a piston moves in a cylinder, and these movements are communicated to a wheel by means of a crank and crank shaft.

Petrol spray is mixed with air and the mixture exploded in a combustion space or chamber above the cylinder. The explosion is brought about by means of an electric spark which passes between two metallic points on a **sparking plug** inserted in the chamber. The entry of the mixture into the combustion chamber is controlled by an inlet **mushroom valve,** so called on account

of its shape, and another similar exhaust valve controls the exit of fired gas from the cylinder. Each valve is kept in place by a spring, except when a rotating **cam** lifts it for the entry of mixture or exit of burnt gas as the case may be.

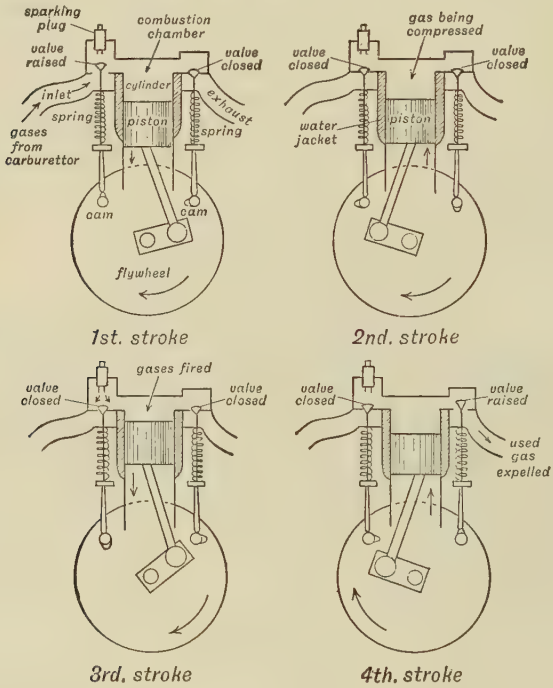


FIG. 173.—THE FOUR-STROKE OR OTTO CYCLE OF THE MOTOR ENGINE.

The machine is called a four-stroke engine because the mixture is actually fired only once in four motions of the piston, two forwards and two backwards.

The cycle of events which occur are as follows :

1st stroke. The piston moves forwards, the inlet valve is raised and the mixture is drawn into the cylinder.

2nd stroke. The piston moves backwards, the mixture is compressed, both valves remain closed.

3rd stroke. The mixture is fired and the piston is pushed forwards, both valves still closed.

4th stroke. The piston moves backwards, the exhaust valve is raised and the burnt gas leaves the cylinder.

The cycle of events is then repeated.

There are other petrol engines in which the necessary events are accomplished in two strokes, but such are only suitable for small motor cycles, their application to motor cars achieving only a limited success.

Apart from the cylinder and piston two other vital parts of a petrol engine are the **carburettor** and the **magneto,** the former delivering a mixture of air and petrol spray to the cylinder, the latter causing an electric spark to fire the mixture of gases just at the correct moment. The mode of working of a magneto is described in Chapter XXVII.

In an aeroplane engine there are several cylinders, arranged radially around the propeller shaft, which is rotated by the properly timed pistons working in conjunction with one another.

A **gas engine** employing coal gas and air works in a manner very similar to that of a petrol engine (Fig. 174). The same

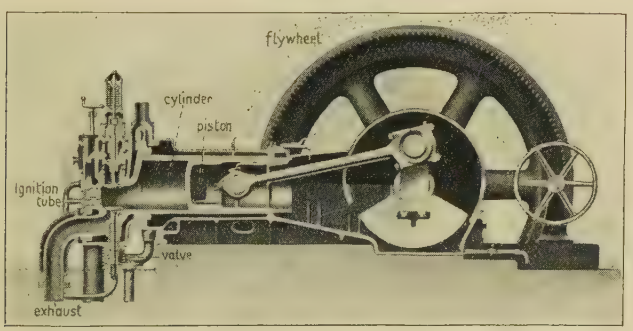


FIG. 174.—A GAS ENGINE AS USED IN FACTORIES.

four-stroke cycle occurs, and valves operated by cams and springs regulate the inlets of gas and exhaust. The ignition or firing of the mixture is effected by means of a red-hot porcelain tube, which is allowed to come into contact with the gaseous mixture at properly

timed intervals by the opening of an adjoining passage. The engine is cooled by water circulating through a space between the cylinder and an outer jacket or covering. **Dr. Otto,** who invented the first satisfactory gas engine in 1876, must be credited with having laid the foundation of the modern internal combustion engine. The sequence of events taking place in the usual four strokes is generally known as the **Otto cycle.**

In **oil engines** an explosive mixture of air and oil spray is used, such mixture being fired by the hot walls of the vaporiser itself. As before there is a four-stroke cycle, but this is modified in a special type of machine called the **Diesel oil engine.** In this, air only is admitted to the cylinder at the first stroke ; during the second stroke this air is strongly compressed, so that the temperature is raised to about 1000° F. At the commencement of the third stroke oil is sprayed into the cylinder and the mixture exploded by its own high temperature. As usual, the last or fourth stroke forces the burnt gas out of the cylinder. The Diesel engine has a higher efficiency and greater economy than that of any other kind of heat engine. It is now being used on ships, many large liners being operated by oil and known as motor ships.

A new type of machine called a **Still engine** employs both oil and steam as sources of energy. The oil is fired inside the cylinder as in the Diesel engine, the steam being used at the correct moment on the other side of the piston to push it back.

With regard to heat engines in general, it must be observed that in all of them only a relatively small part of the heat produced is converted to a suitable form of mechanical energy. At the bottom of the scale is the ordinary steam locomotive, which converts only 5 per cent. of the heat to useful energy, and at the upper end of the scale is the Diesel engine, having an efficiency approaching 40 per cent. A marine steam turbine is nearly, but not quite, as efficient in this respect as a Diesel engine.

CHAPTER XX

THE TRANSMISSION OF HEAT

When possible, heat will pass from a substance of a higher temperature to another at a lower temperature. If no means of escape presents itself, then the heat must stay where it is, but such cases are relatively rare. An apparatus which almost completely prevents the escape of heat is a **vacuum flask,** which consists of an inner vessel nearly surrounded by another outside vessel, the space between the two being nearly a vacuum (Fig. 175). Any hot liquid placed in the inner vessel retains its heat for many hours because the vacuum permits only a very slow escape. The small quantity of heat which does pass proceeds by radiation, but even this is minimised by a reflecting surface of mercury on the inner surface of the larger containing vessel. A very cold substance such as liquid air can also be kept in such a flask, since heat is similarly prevented from passing inwards. The chief function of clothing, particularly in winter, is the retention of the heat in our bodies, but clothing does not do this so efficiently as a vacuum flask for reasons mentioned later.

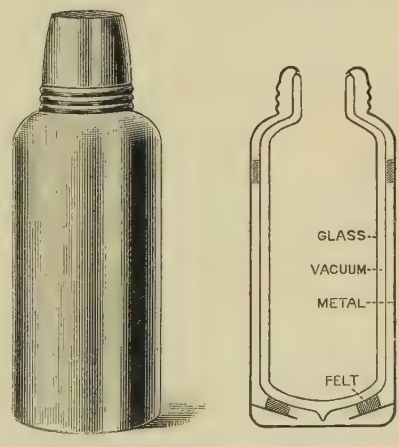


Fig. 175.—A Thermos Flask.

When a hotter substance is in contact with, or near, cooler objects, the heat, or at any rate part of it, generally finds some means of passing to the cooler substances. This transference of heat may take place in one or more of three ways, sometimes in all three ways operating together, according to the circumstances.

Consider the case of a kettle containing water placed over an ordinary gas burner. The heat supplied by the burning gas warms the outer surface of the metallic substance composing the kettle. Each particle of metal *by contact* passes heat to the particle next to it, and very quickly the inner surface of the

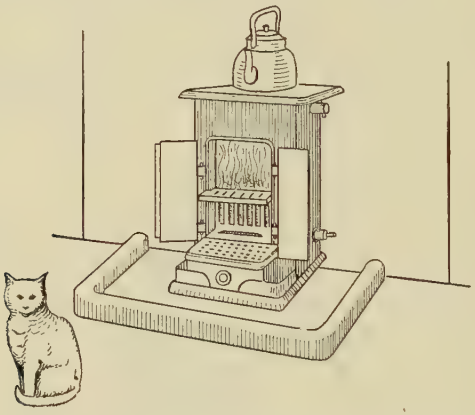


FIG. 176.—THE WAYS IN WHICH HEAT IS TRANSMITTED.
THE KETTLE RECEIVES HEAT FROM THE FIRE BY CONDUCTION, THE WATER IN IT IS HEATED BY CONVECTION, WHILE THE CAT RECEIVES HEAT BY RADIATION.

kettle is heated strongly. When heat is transmitted through a solid body in this way the process is known as **conduction.** The water near the bottom of the kettle becomes heated, but in this case, the heated particles being less dense than the cooler particles above, they rise through the water and take their heat with them. In this way a current or circulation of heated particles is produced, and heat transferred from one place to another in this way is said to be transmitted by **convection.** It is obvious that such convection currents occur only in fluids. Unlike solids, liquids and gases are warmed by convection, not by conduction. Now, all of the heat emitted by the burning gas is not obtained by the

kettle and water; some of it gives rise to convection currents in the air, but some also passes through the space around the kettle by a process termed **radiation.** If the burning gas is turned off, and a few minutes later a hand is placed an inch or two in front of the kettle, the hand experiences the sensation of warmth because it receives radiant heat which is being radiated in all directions through the space around the kettle. This is not a case of convection, and the *air itself is not appreciably warmed by the radiant heat which passes through it.*

This important fact should be remembered as it explains many things in connection with the atmosphere and climate. Though the air around him may be cold, a person standing in the sunshine at the top of a mountain may be uncomfortably warm. The sun warms *him*, but not the air around him. Heat from the sun reaches the earth after traversing about 93,000,000 miles of space in which there is no ordinary matter. Radiant heat is a kind of wave-motion proceeding through the ether which occupies all space, heat waves being closely related to light waves, as described in Chapter XXII, which deals with light and colour.

CLOTHING AND DOMESTIC HEATING

We must now consider examples of practical consequences arising from the three modes of heat transference—conduction, convection, and radiation.

Solid substances which permit heat to pass easily or rapidly through them are said to be good conductors; others which do not permit such easy passage of heat are bad conductors. Most good conductors are metals or metallic alloys, and for this reason such substances as copper, iron, brass, and aluminium are employed extensively in kettles, saucepans, preserving pans, and many other domestic appliances. Because these substances easily conduct heat, they feel cold when in contact with our bodies; heat is rapidly withdrawn from us, and its loss produces the sensation of 'coldness.' Sea or tap water also feels cold, because convection currents occurring in it quickly take heat from the body.

On the other hand, wood and fabrics made of wool, cotton, or silk, are classed as bad conductors ; they do not feel cold because they do not conduct heat away sufficiently well for us to experience a distinct drop in bodily temperature. The temperature of the body must be maintained, and this is done partly by taking sufficient quantities of heat-producing foods, such as the carbohydrates sugar and fat, partly by exercise, and partly by the use of suitable non-conducting articles of clothing. Silk, wool, and to a lesser extent cotton, make clothes which are fairly efficient as far as non-conducting properties are concerned. A slow loss of heat takes place, however, since small convection currents are set up in the air occupying the minute spaces or pores in the material (Fig. 177). Leather, which is relatively non-porous, is worn by aviators and motorists.

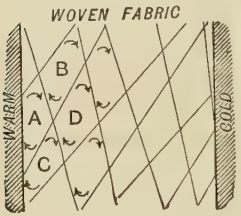


FIG. 177.—CONVECTION CURRENTS IN AIR CAVITIES OF FABRICS.

THE FIBRES BETWEEN THE CAVITIES (*A*, *B*, *C* AND *D*) BECOME WARMED BY THE AIR AND PASS HEAT TO ADJOINING CAVITIES.

The relation between clothing and radiant heat must not be overlooked. Black or dark coloured clothes generally absorb more radiant heat than white or light coloured clothes, hence the use in summer of white straw hats, and light coloured flannels, which act not only as poor conductors, preventing the penetration of the sun's heat, but as reflectors as well. Rays of heat can be sent back or **reflected** just as light rays are, and the reflecting properties of a hat are increased if it has a shiny surface ; even a black silk hat being cooler than one composed of dull black felt. Similarly, well polished black shoes may be cooler than others made of dull light-coloured suede.

The primary reason for all domestic and public heating is the maintenance of the correct bodily temperature, and it may be as well to consider the usual methods by which the required result is obtained. An ordinary coal fire warms our rooms and our persons partly by radiation and partly by convection. Only the actual fireplace itself and objects such as a poker placed in the fire are heated by conduction. The air in the room is warmed by convection currents, which also deliver heat to objects including

ourselves placed at various positions in the room. Heat is also taken to various parts of the room by radiation, and this mode of transmission is more perceptible if we deliberately stand in front of the fire. The use of a fire screen prevents transmission by radiation, and if a glass screen which is transparent to light but absorbs heat rays is used, we can enjoy the appearance of the fire without experiencing too much warmth.

In the older type of grate much heat escaped as convection currents in gases passing up the chimney, but more modern types of fireplaces seek to minimise this loss by having the back part inclined forwards, thus directing the heat forwards rather than upwards. Electric fires are provided with polished curved reflectors placed at the back so that radiant heat is reflected forwards (Fig. 247).

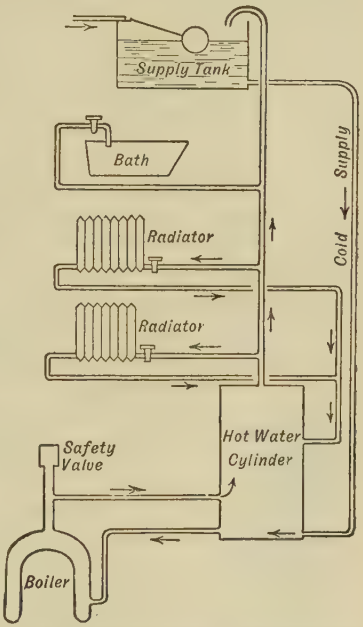


FIG. 178.—DIAGRAM SHOWING THE ARRANGEMENT OF PIPES, ETC., IN CENTRAL HEATING.
CONVECTION CURRENT INDICATED BY ARROWS.

In the system known as **central heating**, common in hotels, schools, large houses, etc., hot water circulates through a series of pipes, and the process is one of convection combined with radiation (Fig. 178). Water is heated by a boiler in the basement, and the convection currents cause heat to be taken to the top of the building and the heated water circulates through various **radiators** in rooms on different floors. The great advantage of this mode of heating is the even distribution of temperature obtained. A person does not go from a hot sitting room to a much colder bedroom, and the rooms are kept at a fairly constant temperature day and night.

Though smaller residences do not possess central heating, practically all houses of recent construction are supplied with a hot-water system which, operating in a similar way by convection, yields a constant supply of hot water for the bathroom and kitchen. The upkeep is quite economical, since any modern slow combustion stove placed in the kitchen or scullery consumes cheap fuel, such as coke mixed with household refuse. In winter these domestic boilers help to keep the water in other pipes from freezing, but where pipes extend along relatively exposed positions, such as in a loft or cellar, they should be covered by such non-conducting materials as felt or sacking. Loss of heat from the water in the pipes is thus lessened, and a 'burst' caused by the expansion which takes place when water changes to ice is not so likely to occur.

Compartments in trains are warmed by steam forced along pipes in and below the carriages.

Before we consider other important cases of convection and radiation, some practical applications of conduction must be noted. Metal teapots should be fitted with wooden handles or have handles effectively protected from the heat by porcelain or other poorly conducting substances. The relatively non-conducting nature of porcelain and china ware is illustrated by the fact that no special handles are necessary in the case of china teapots, cups, and jugs. Most rocks are bad conductors of heat, so that slabs of fine grained sandstone, ganister, dolomite, and others are used for the linings of furnaces. So called 'fire' clays produce the brick-like material generally forming the back, sides, and base of a modern fireplace. These substances are not only bad conductors, but also withstand a very high temperature without undergoing chemical alteration.

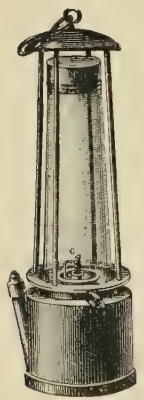


Fig. 179.—A Miner's Safety Lamp.

A particularly interesting and useful case of rapid conduction by metal is afforded by the **miners' safety lamp** (Fig. 179). Copper gauze, if pressed down upon the flame of a gas burner, does not allow the flame to pass through it, although the gas itself proceeds through the meshes of the

gauze. So effectively is the heat conducted away from the spot that the temperature of the gas is lowered below the *ignition point* as it passes through the gauze, and only when the heated metal becomes red hot will the gas above it ignite. In the miners' safety lamp, invented by **Sir Humphry Davy,** the flame of the lamp is surrounded by glass, but above this is a space bounded all round by fine copper gauze. Inflammable gases which may be present in a pit can pass through and burn inside the lamp, but the flame cannot get through to the outside and so fire an explosive mixture of gases.

VENTILATION AND WINDS

The fluid nature of air permits expanded warm particles to rise and cooler denser particles to sink. When warmer air rises, cooler air flows in to take its place, and a general convection current or circulation is produced. This occurs on a small scale in any well ventilated room (Fig. 180), and on a very large scale over those enormous expanses of the earth's surface where the chief permanent winds circulate (Fig. 181).

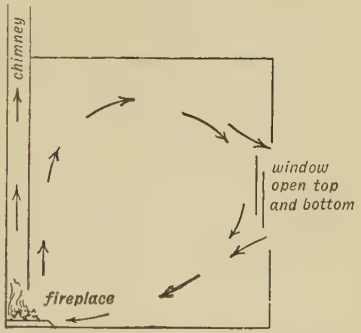


FIG. 180.—A ROOM VENTILATED BY CONVECTION CURRENTS CAUSED BY A FIRE.

In a room the exhaled breath from people's lungs is slightly warmer and less dense than the rest of the air, consequently such bad air rises to the upper part of the room. For this reason adjustable ventilators or small windows should be placed fairly high up in the wall, and as the bad air escapes through these, fresh air enters by any of the openings lower down, such as the space between the door and the floor. This often means an unpleasant draught, hence it is better to admit fresh air by an opening in the wall half-way towards the ceiling. An ordinary coal fire affords one of the best means of ventilation, since it

causes a strong up-draught in the chimney, but even then there should be some ventilator or opening placed near the top of the room. In former times mines were ventilated by placing a fire at the bottom of one shaft, fresh air being forced down another shaft to take the place of that ascending above the fire, but at the present time powerful fans operated by steam or electricity at the pit-head produce the necessary current of air through the workings of the mine.

Enormous convection currents circulating along definite routes above the earth's surface are known as **permanent winds** since they continue without interruption, for the simple reason that the conditions which produce them are permanent (Fig. 181). The most typical of such air currents blow across land and sea within the tropics and are called **trade winds** because of their very beneficial aid to shipping, particularly in the days when sailing vessels were the only kind crossing the ocean. Air obtains its heat, and consequently its temperature, from the land, sea, and other objects with which it comes in contact. The sun's rays warm the land and water, and these warm the air touching them. Along a broad belt extending a few degrees of latitude each side of the equator the air thus becomes heated and rises vertically. A person in this belt experiences no *horizontal* motion of air commonly called a wind, and the belt is known as the region of **equatorial calms,** often called the doldrums. The cooler air a few degrees farther north and south flows steadily in towards the equator to take the place of the ascending equatorial air. These inflowing trade winds would blow directly from the north and from the south if the earth did not rotate, but this motion of the earth causes the trade winds to flow from the north-east and south-west respectively. Winds are named according to the direction from which they blow. These particular winds carry enormous quantities of water vapour obtained from the ocean which eventually produces the heavy rainfall in countries lying in their track, for example, Brazil in South America.

What happens to the heated equatorial air after it has ascended some distance in the atmosphere ? Some of it proceeds towards the north-east and some towards the south-east, and eventually it descends again at the polar regions where there are **polar calms,**

the air movement being vertical, not horizontal. Some of this air descends a little north of the Tropic of Cancer and some a little south of the Tropic of Capricorn, hence there are two other belts of calms, one near either tropic. North and south beyond the tropics, in more temperate latitudes, other convection currents produce the permanent **westerly winds,** which include those

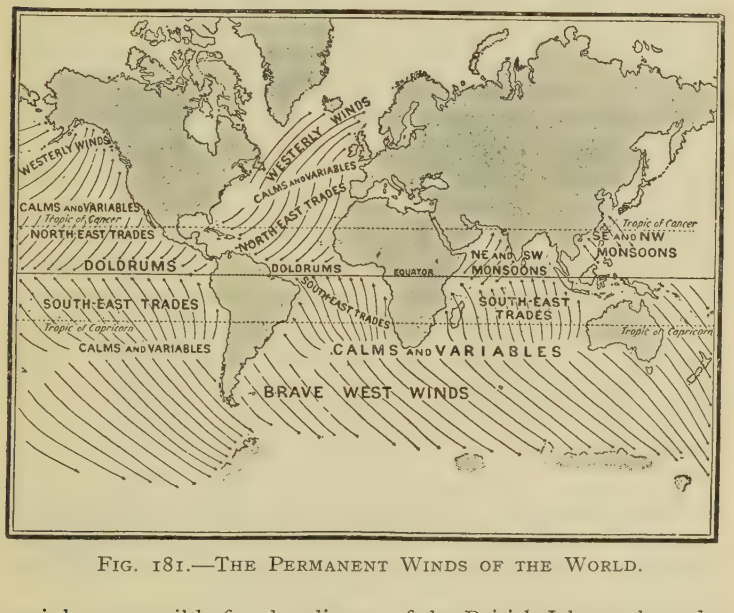


FIG. 181.—THE PERMANENT WINDS OF THE WORLD.

mainly responsible for the climate of the British Isles and north-west Europe. These westerly winds are more stable in the southern hemisphere owing to the greater extent of ocean there, the more diverse mixture of land and sea in the northern hemisphere having a tendency to modify these winds. The strong westerly winds of the south are called the **roaring forties**, since they occur in latitudes roughly 40° south. In southern Asia, where diversity of land and sea again modifies winds, convection currents result in the monsoon changes mentioned in the previous chapter, where land and sea breezes were also described, since such cases are brought about largely by specific heat as well as

convection. Of course, the whole convection wind system moves slightly northwards and southwards according to the position of the sun at different times of the year.

RADIATION AND THE THERMOPILE

Life is possible on the earth because of the heat received from the sun, and all of this heat reaches us by radiation. We owe our very existence to waves of radiant heat. If the earth were a flat table at right angles to the sun's rays, all parts of it would receive the same amount of heat per square mile, but since the earth is not flat but curved, the amount of heat received per square mile varies with latitude and with the season. The sun's rays strike more obliquely in higher latitudes than they do near the equator, and the effect of this has been discussed in Chapter II, where features resulting from the earth's shape were described.

Since the sun's rays do not appreciably warm the air, a thermometer placed in direct sunshine measures the temperature of itself heated by the sun, not the temperature of the air. For this reason all thermometers used in connection with meteorological reports concerning air conditions are placed in a Stevenson's screen. If it is desired to measure the solar radiation, or heat of the sun's rays, a special radiation thermometer having a dull blackened bulb is employed. Such a thermometer reflects very little of the radiant heat, and quite often it registers a temperature of 120° F. or more. If the air received its heat directly from the sun's rays, summer conditions would be unbearable.

In reality, an extremely small fraction of the sun's total heat is received by the earth, for two reasons—relatively a few only of the rays strike the earth, and the amount of energy received from such rays is less the greater the distance an object is placed from the source of heat. We are at an enormous distance from the sun. It can be proved experimentally that the amount of energy received varies inversely with the square of the distance. This is another case of the inverse square law so often met with in natural phenomena.

This important rule and many other interesting facts concerning radiant heat can be verified by means of an apparatus

called a **thermopile** (Fig. 182). This consists of a number of metallic couples each composed of a small bar of antimony joined at one end to a similar bar of bismuth. Such a couple has the property of producing an electric current when the junction of the two metals is heated while the remote ends are connected by a wire. This is an example of the conversion of heat energy into that of electricity. The effect can be increased by having a large number of such couples joined together in series or one after another, and the effect can be rendered visible if the electric current produced is passed through a sensitive galvanometer. The thermopile has several of these couples, and one side of the arrangement is

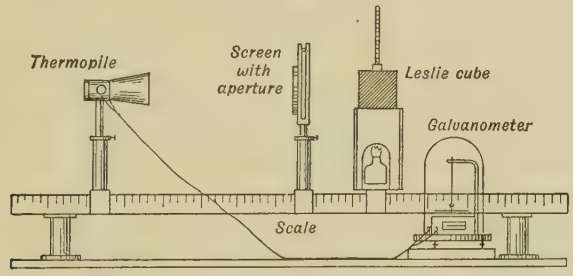


FIG. 182.—APPARATUS FOR THE STUDY OF RADIANT HEAT.

fitted with a conical funnel which concentrates heat rays upon the ends of the metallic couples.

In experiments on radiant heat, a **Leslie cube** or hollow metal cube containing hot water supplies the heat waves. The thermopile is placed at a definite distance from the cube, and the deflection of the galvanometer needle is noted. Then with the water at the same temperature the thermopile is placed at twice the distance and the movement of the galvanometer noted again. It is found that at twice the distance only $\frac{1}{4}$ of the effect is produced, the radiant heat captured being only $\frac{1}{4}$ of that received before. At three times the distance only $\frac{1}{9}$ of the heat is received, though the hot water remains at the same temperature. Hence the law of inverse squares.

The Leslie cube has four vertical faces, two white and two black. One of the white faces is polished, the other dull; similarly with the black faces. Now though all of the faces must be

at the same temperature it is found that they do not all radiate heat equally well. The dull black surface radiates heat better than the others; the white polished face gives the smallest result. From this it follows that radiators used in the central heating of buildings operate best when they are dull black, and a silver teapot retains its heat longer when kept well polished. In general, it is found that good radiators also absorb heat well, and *vice versa*.

A thermopile can be used in experiments on **diathermancy,** or the transparency of various substances to heat rays. A piece of glass placed between the thermopile and the Leslie cube allows light to pass through but stops most of the heat rays, as shown by the effect on the galvanometer. On the other hand, a slab of rock salt of the same thickness permits nearly all the heat rays to pass through it, though it is almost opaque to light. Dry air is very diathermanous, but water vapour in air stops the passage of a large proportion of the heat rays. A clear starlit night is colder than a cloudy one at the same time of the year, because clouds and mists prevent excessive radiation of heat from the earth. But it must be remembered that the temperature of the source of heat is a factor in diathermancy. A large proportion of heat rays from the sun can pass through the glass of a greenhouse, but heat radiated at night by objects in the greenhouse cannot escape, hence the temperature is properly maintained.

CHAPTER XXI

HEAT AND CHANGE OF PHYSICAL STATE

The substance we call water also exists in the solid form called ice, and in the gaseous form called steam. All three forms are identical in chemical composition, though each has different physical properties; for example, water is the heaviest of the three, steam is the lightest, bulk for bulk. The physical state, whether solid, liquid, or gaseous of this substance, is determined by the temperature and the pressure upon it. Thus at ordinary atmospheric pressure and at temperatures below 0° Centigrade the substance is solid ice, between 0° C. and 100° C. it is liquid water, and above 100° C. it is gaseous steam. At normal pressure 0° C. is called the melting point of ice, and 100° C. is known as the boiling point of water. An alteration in the pressure slightly alters the melting and boiling points. An increase of pressure lowers the melting point of ice but raises the boiling point of water as we shall see later. An iron weight suspended by a wire over a block of ice slowly pulls the wire through it, since its pressure added to that of the atmosphere causes the ice immediately below the wire to become liquid (Fig. 183). The new water thus formed emerges from beneath the wire and immediately re-freezes.

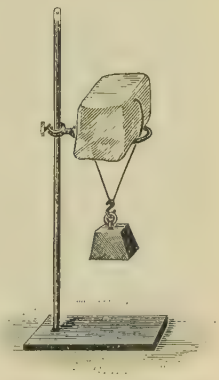


Fig. 183.—An experiment to illustrate Regelation.

This process of re-freezing is known by its French name of **regelation.** The ice of a glacier pressed against the sides of its valley

melts, and in this way the glacier adapts itself to the shape of the valley. The conversion of snow in a mountain snowfield to glacier ice is another example of regelation; the lower pressed snow melts, emerges from the mass, and then immediately re-freezes, forming a glacier. When snow is just about 0° C. in temperature a little pressure of the hand suffices to melt it and then on relaxing

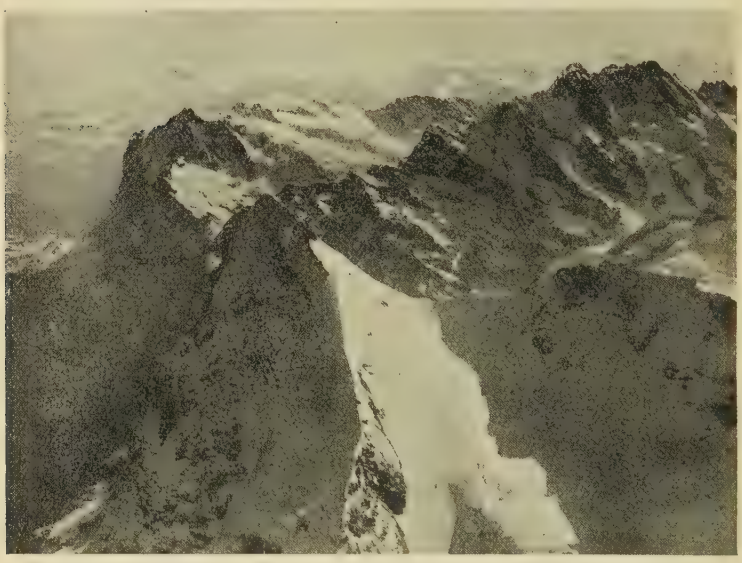


Fig. 184.—An Alpine Snowfield.
Some Peaks and Crests of the Bernese Oberland.
(*Aerial photograph by Lieutenant Mittelholzer.*)
(By courtesy of the Swiss Federal Railways.)

the pressure it re-freezes forming a snowball. On a very cold winter's day when the temperature is some degrees below 0° it is not easy to make a snowball, more pressure being necessary. Snow itself consists of a loose mass of beautifully shaped aggregates of ice crystals.

Ice is lighter than water, and this means that when water changes to ice an increase of volume takes place. This is of considerable practical importance. The expansion accompanying

the formation of ice in water pipes exerts great pressure and may burst a pipe at a weak spot, and then, when a thaw comes and the ice melts, a bad leak is found. Icebergs, being slightly lighter than an equivalent volume of water, float with only a small fraction of their bulk above the sea-level, thus becoming a source of danger to shipping (Fig. 142). When water in a pond freezes the ice collects at the top, leaving warmer denser water below. In the case of snow, air being present as well as ice, the volume is even greater, and in meteorological work, snowfall is estimated as rain by allowing the snow to melt before it is measured. A fairly deep fall of snow may be equivalent to less than an inch of rain.

HEAT ABSORBED BY MELTING ICE

In connection with the melting of ice there are some quantitative relations which must be considered carefully. If some *dry* ice is placed in a vessel and gently warmed the ice slowly melts. A thermometer placed in the water being formed shows that its temperature remains at 0° C. so long as any ice remains unmelted. Only after all the ice has been changed to water does the temperature begin to rise. Yet heat has been steadily supplied the whole time. What has happened to this heat? It is obvious that a certain quantity of heat has been used up in the process of converting ice to water. Heat absorbed in this way is said to be **latent**, since it does not make itself apparent by a rise in temperature. It requires energy to change a solid to a liquid, and this energy is supplied in the form of latent heat. The number of heat units required to convert one gram of ice to water, without changing the temperature, is a quantity known as the **latent heat of fusion of ice.**

This quantity can be found quite easily by putting some dry ice into a calorimeter containing a certain quantity of water (Fig. 185). Heat passes from the water to the ice, which melts and adds so much new water. While the ice is melting the temperature falls as shown by a thermometer, and by noting the total fall of temperature we can calculate how many heat units have been used to convert the ice to water, provided the weight

of water before and after the experiment is known. If the weight of water were 100 gm. at first and 110 gm. afterwards, it is clear that 10 gm. of ice were placed in the water.

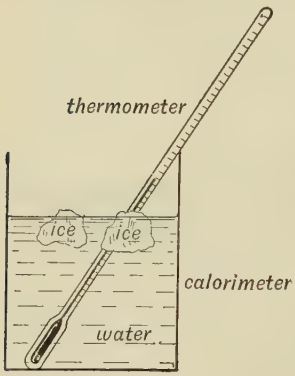


FIG. 185.—APPARATUS FOR THE DETERMINATION OF THE LATENT HEAT OF FUSION OF ICE.

Let us suppose that the temperature of the water was 15° C. before the ice was added, and 6·4° when all the ice had just melted. Now the heat units lost by the water are found by multiplying its original weight by the fall in temperature. In this case we have $100 \times (15 - 6{\cdot}4) = 860$ units which have been absorbed in melting 10 gm. of ice, *and in raising* 10 *gm. of new water from* 0° *to* 6·4° *C.* Therefore to melt one gram of ice the heat units required are $\frac{860}{10} - 6{\cdot}4$, the rise in temperature of the new gram of water being deducted.

$\frac{860}{10} - 6{\cdot}4$ gives **nearly 80 as the latent heat of ice.**

About 80 calories are required every time one gram of ice at 0° C. is converted to water still at 0° C.

In experiments on latent heat, the copper calorimeter loses or receives so much heat; in cases where ice is used it loses some, and allowance must be made for this. As the specific heat of copper is about 0·1, it is usual to weigh the calorimeter, multiply the weight by 0·1, and call the quantity obtained so much extra water, for heating up the calorimeter itself is equivalent to this quantity of water. Thus in the case given above, suppose the calorimeter weighed 50 gm. and 95 gm. of actual water were placed in it. The 50 gm. of copper are equivalent to another 5 gm. of water, making 100 gm. in all, and in this case the figure ' 5 ' is the **water equivalent** of the calorimeter.

Eighty calories per gram is a fairly large quantity and explains why large lumps of ice keep fish and other commodities cool for a long time. These things give their heat to the ice and until

all of it has melted the temperature remains very low. The considerable drop in air temperature which produces fogs in the iceberg region off Newfoundland, etc., is also due to the absorption of latent heat by melting ice. If we desire to keep ice for some time, it must be wrapped in some non-conducting material, such as a blanket, cotton wool, or sawdust, which will prevent heat getting to it.

When other solids melt, latent heat is similarly absorbed in the process, but most substances do not require so much heat per gram as ice does. For example, paraffin wax melts at 52° C. and each gram requires only 35 calories to melt it. In the case of sulphur, a gram requires only 9·4 calories.

In spite of fogs near icebergs, it is fortunate that the latent heat of ice is relatively high, since a low value would mean rapid melting of snow on mountains, causing disastrous floods, and with a fall of temperature ponds and lakes would quickly become completely frozen, with destruction of animal life, and burst pipes in houses would be very common. Latent heat works both ways; water gives out 80 calories per gram when it becomes ice, and if the latent heat were much less ponds would more easily freeze (and melt).

HEAT ABSORBED WHEN WATER BOILS

When any liquid is changed to a gas, energy in the form of heat is used up without a change of temperature taking place. Thus when water at 100° C. becomes steam at the same temperature, the heat absorbed in the conversion of water to steam is latent, and in this case is described as **latent heat of vaporisation.** If some steam is passed into a definite weight of water in a calorimeter (Fig. 186) and the temperatures before and after adding the steam are noted, the actual amount of heat given out by every gram of steam at 100° in becoming water at 100° can be ascertained. If the water is weighed again the extra weight is that due to steam added. Now the heat lost by the steam is equal to that gained by the water *less a small amount supplied by a few grams of new hot water in cooling from* 100° *to the final temperature* of the mixture. An allowance must be made for this as shown

below. Let us suppose that 100 gm. of water at 15° C. were used originally (including the water equivalent of the calorimeter), and that 10 gm. of steam were added causing the final temperature to be 71·5° C. The heat units gained by the water = $100 \times (71{\cdot}5 - 15) = 5650$, and these were supplied by 10 gm. of steam in becoming water and by 10 gm. of hot water in cooling from 100° to 71·5° C., a quantity which must be deducted. Therefore 10 grams of steam in becoming water yield :

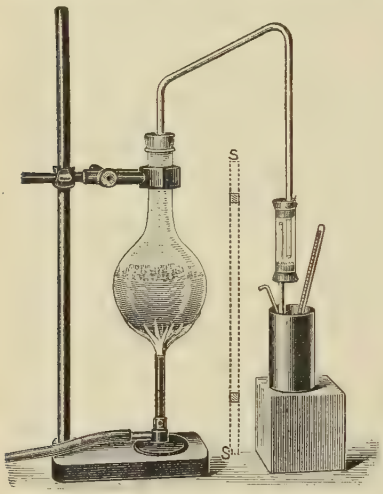


FIG. 186.—APPARATUS FOR THE DETERMINATION OF THE LATENT HEAT OF VAPORISATION OF STEAM.

$$5650 - (100 - 71{\cdot}5) \times 10$$
$$= 5650 - 285 = 5365.$$

Thus every gram of steam yields about 536 calories in becoming water, and conversely it requires about 536 calories to convert every gram of water to steam without a change of temperature. **The quantity 536 is known as the latent heat of steam.** In experiments of this nature it is important to see that no hot water passes in with the steam, hence the use of a suitable trap to catch water formed by condensing steam.

536 is a very big number and explains why so much fuel must be used to convert water to steam in a locomotive or other steam engine. On the other hand, quite a small quantity of steam gives out sufficient heat to warm a railway carriage.

The temperature at which water or other liquids boil depends upon the pressure exerted upon it ; in the case of water the boiling point is 100° C. *under normal atmospheric pressure*, which in a barometer is represented by a column of mercury 30 inches in height. At the top of a high mountain water boils at a lower temperature than 100° C. because the pressure of the atmosphere

on the water is reduced. In a deep valley below sea-level, such as that of the Jordan in Palestine, the pressure is greater than normal, hence water boils there at a temperature higher than 100° C. Evidently water boils at a temperature when the pressure of its steam is just in excess of that of the atmosphere pressing upon it. The air pressure and the steam pressure oppose each other, and provided sufficient heat is supplied, the air will eventually lose the contest and the water will boil, its steam will escape.

The influence of pressure on the boiling point of a liquid is very important. Water in a boiler of a steam engine must be heated beyond 100° C. to overcome the pressure of the steam in the boiler itself. Both water and steam in a closed space become superheated and the pressure increases according to Charles's Law as we have seen.

EVAPORATION, CONDENSATION, AND WEATHER

When water is being heated in a kettle, the source of heat is generally placed below the kettle; hence water at the bottom becomes hotter sooner than that at the top, though convection is endeavouring to heat all parts. After a while, bubbles of steam form at the bottom, rise through the water, reach cooler layers above, and are converted to water again. This process is accompanied by a characteristic noise known as *singing*. A little later the water becomes more uniformly heated, the singing becomes less pronounced, and the water boils.

In boiling, all parts of the liquid are concerned, and a definite temperature is necessary, but liquids may become vapour at lower temperatures by a process known as **evaporation**, *which takes place at the surface only*. Thus water exposed to the air evaporates slowly, and since the process occurs only at the surface, the rate of evaporation depends to some extent upon the shape of the containing vessel. A gallon of water will disappear more quickly from a shallow bath than it will from a tall jug, but the rate of evaporation is mainly determined by another important factor, namely, *the condition of the air at the time*. If the air holds as much water vapour as it can do it is said to be

saturated and will take no more. Water exposed to such air will remain as it is; no more will evaporate until the air conditions become unsaturated. A rise in temperature will render the air unsaturated and then evaporation will proceed from the water.

If a fall of temperature occurs in air already saturated, then some of the water vapour, by the process called **condensation,** is thrown out as drops of water, and this explains the formation of rain, snow, mists, fogs, and the deposit of a film of moisture on walls and furniture on certain days when the air happens to be saturated and is slightly cooled. It is important to realise that on a warm summer's day the air holds quite a lot of water vapour, but it may not be saturated because the temperature is high. On such a day a tumbler containing cold water cools the air near it, so that a film of moisture is deposited from this air on the *outside* of the tumbler. The air near the tumbler has been cooled and brought below saturation point. The formation of **dew** is similarly caused by air being cooled below the saturation temperature by the cold ground, and the deposit of dew will be greatest on those objects which radiate heat best, and consequently become cooled quickly. When the air is nearly saturated a slight fall of temperature leads to the deposit of moisture, but when it is far from being saturated a big drop in temperature is necessary. The temperature at which dew or moisture is deposited is called the **dew point,** and it follows from what has just been said that the dew point varies considerably. In winter this temperature may be below 0° C., in which case a solid white **frost** is deposited.

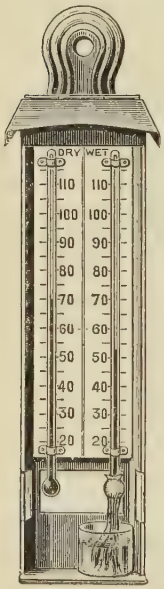


FIG. 187.—WET AND DRY BULB HYGROMETER.

The condition of the air, whether it is saturated or not, can be ascertained by the use of an instrument known as a **hygrometer,** so named because it indicates the amount of moisture in air. A common form of such instrument consists of two thermometers placed side by side, but a slight distance apart

(Fig. 187). One of these thermometers has its bulb covered by muslin or other porous material dipping into water in a small vessel. This is generally called the wet thermometer, to distinguish it from the other which has no such arrangement attached to it. The porous fabric ' sucks up ' water and causes it to evaporate, and as evaporation requires latent heat, a fall in temperature occurs, consequently the more the air is unsaturated the greater the evaporation and the lower the temperature indicated by the wet thermometer. The other instrument measures the ordinary temperature of the air at the time. If the air is really saturated, it is at the dew point, and the two thermometers give the same reading, but if the air is far from saturation the two thermometers give very different readings. If the actual dew point is to be determined by means of this instrument reference must be made to certain tables, but by the use of **Daniell's hygrometer** (Fig. 188) the dew point can be found directly by experiment. In this a glass bulb (*B*) is covered with muslin and a little ether or other volatile substance is poured on it. By evaporation the temperature is lowered and moisture is deposited upon a second bulb (*A*) containing a thermometer which shows the temperature at which the moisture begins to appear.

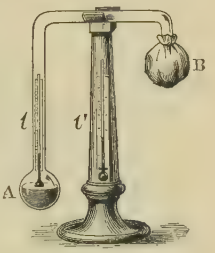


FIG. 188.—DANIELL'S HYGROMETER.

When large masses of air are cooled sufficiently, water vapour is changed to liquid or condensed to water, and **clouds** are formed. The drops of water are at first too small to fall as rain, but as further cooling and consequent condensation proceed, the drops become larger and eventually fall. Air is cooled by its rising upwards; such ascending air reaches altitudes where the pressure is reduced and it expands. *When any gas expands heat is absorbed and the temperature falls.* Conversely, descending air contracts and gives out heat. Any cause which deflects air upwards leads to its being cooled by expansion, and this explains why mountain ranges are generally the places where there are heavy falls of rain or snow. The western side of the British Isles has a much heavier rainfall than the eastern side because

the high land there deflects the westerly winds upwards (Fig. 189). Other factors may produce similar effects. There are no mountains in the central portion of the Amazon basin in South

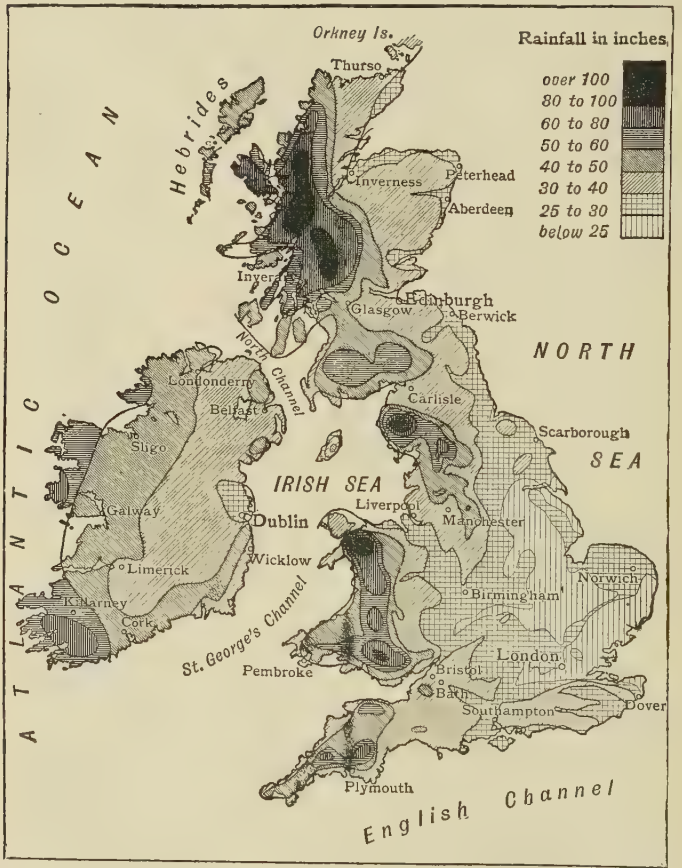


FIG. 189.—MAP SHOWING THE AVERAGE ANNUAL RAINFALL OF THE BRITISH ISLES.

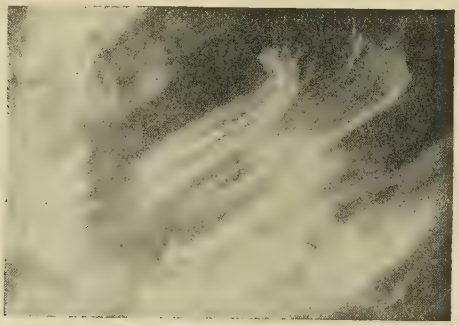
America, but the air there ascends because the heated ground causes an updraught; consequently there is a heavy rainfall in that region.

Ascent of air, then, is the main cause of cloud formation and of rain. The highest clouds, at an altitude of about six or seven miles, appear as white feathery masses known as **cirrus.** These are composed of ice particles since at that height the temperature is below 0° C. The temperature, pressure, and humidity of the upper air has been investigated by means of sounding balloons which carry small but efficient instruments up with them. The balloons burst but the protected self-registering instruments fall, are recovered, and their records obtained. It is now known that *all of the conditions which we call weather are produced within six or seven miles of the earth's surface.* Beyond this altitude there is a region free from clouds but intensely cold.

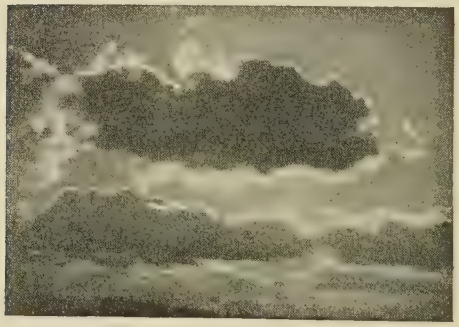
In summer we often see great white billowy clouds called **cumulus,** and these may either slowly disappear or develop into darker clouds called **cumulo-nimbus,** almost black at the base and usually associated with thunderstorms and heavy falls of rain. The basal parts of clouds of this type are roughly at a height of $\frac{3}{4}$ mile, though the upper whiter portions may extend to 3 miles. At greater heights a combination of cirrus and cumulus occur, and these are rather curved white clouds, sometimes producing the appearance of 'mackerel sky.' An alternative name for these is **alto-cumulus.** The long low-lying clouds often seen at sunset in summer are called **stratus.**

Condensation of water vapour depends upon there being dust or other particles in the air. Each drop of rain is formed around such a small nucleus, and, in the vicinity of large cities where great quantities of smoke are passed into the air, a fog may be produced. Fogs and mists are formed near the ground and result from the fact that the air just above the ground happens to be cooler than that above. Water is normally transparent, but the opaque character of fog particles is due to the large number of impurities in the air, chiefly sulphur, carbon, and ammonia.

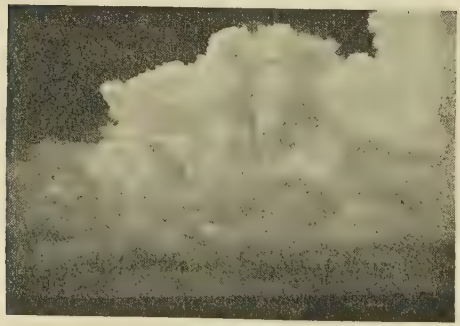
When the temperature is sufficiently low, snow may fall instead of rain, and in certain conditions, particularly those associated with thunderstorms, hail is produced. Some hailstones show a structure composed of concentric layers of ice, indicating repeated alteration of temperature due to different levels reached as the



"Mares Tails"—Cirrus



Cumulus



Cumulo-Nimbus

Fig. 190.—Types of Clouds.
(*From photographs by Mr. G. A. Clarke, Aberdeen.*)

hailstone has repeatedly fallen and then carried upwards again. Vertical oscillations of this kind also influence the size of hailstones; in some thunderstorms hail as large as walnuts falls and does great damage to vineyards, greenhouses, etc.

SOME PRACTICAL RESULTS OF LATENT HEAT OF VAPORISATION

Heat must be supplied to a liquid in order to vaporise it, and this heat is generally obtained from surrounding objects; hence evaporation is accompanied by a fall of temperature. A surgeon employs an ether spray to produce local anaesthesia, or insensibility to pain, in some minor operations. Ether is sprayed upon

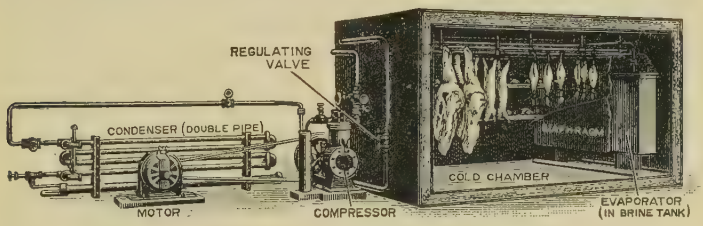


FIG. 191.—REFRIGERATING APPARATUS AND COLD STORAGE FOR THE PRESERVATION OF MEAT.
A LOW TEMPERATURE IS PRODUCED BY THE EVAPORATION OF LIQUID AMMONIA.

the affected place and its rapid evaporation takes sufficient heat from the place to produce a numbness or temporary insensibility. Butter may be kept cool by placing it under wire netting supporting a porous fabric, the ends of which are immersed in water. The arrangement is similar to the wet bulb thermometer of a hygrometer, evaporation of the water producing a fall of temperature. A person receives a chill if he sits about in wet clothes, because, as these clothes dry by evaporation of the water, much heat is taken from his body to supply the necessary latent heat. He should either remove the clothes before they dry, or if this is not possible, he should take sufficient exercise to generate heat to balance that lost.

In commercial activities, large quantities of artificially produced ice are employed, and in other cases air at a very low temperature

is necessary. For example, the meat exported from the Argentine, New Zealand, etc., is carried by ships specially fitted with refrigerators or cold chambers in which a low temperature is produced artificially. In all warm countries large quantities of meat, fish, game, and other perishable goods must be preserved in a similar manner. Modern machinery used to produce low temperatures makes use of two facts described above, (1) the cooling of a gas by expansion, dynamical cooling as it is sometimes called, and (2) the heat absorbed by a liquid as it evaporates.

The substance commonly employed is liquid ammonia, and this is obtained by allowing ammonia gas to expand (compare liquid air, Chapter XXX). By means of a pump producing a suction effect in the space above some liquid ammonia, some of it is vaporised, and this leaves the remaining liquid cooler, and, of course, the process can be continued. If the liquid ammonia is placed in pipes surrounded by a brine solution, the latter is cooled and its influence can be employed either to produce quantities of artificial ice or to cool a chamber containing meat or other perishable goods. Solutions of brine or of calcium chloride remain liquid at temperatures below 0° C., and hence are useful as a means of producing low temperatures by convection. Other details of an ammonia refrigerating plant are given in Chapter XXXVI.

CHAPTER XXII

LIGHT AND COLOUR

WAVES IN MATTER AND IN ETHER

We see things because they send light to our eyes. *Light itself is not visible* ; it is the object illumined by the light that is seen. When we speak of ' seeing a light ' we are not stating things correctly, the things seen being the white-hot particles of matter which originate the light. A candle flame is visible because its heated particles emit light, but a house is seen because it reflects light obtained from the sun during the daytime, or from a lamp or the moon at night. The sun, stars, candle flames, and electric lamps are all self-luminous or give out light of their own, but most relatively cold objects—the moon, houses, and nearly all the objects we come in contact with in daily life—are not self-luminous ; they are seen because they reflect light obtained from some luminous source.

In a self-luminous object, light is nearly always accompanied by heat and by other radiations which can neither be seen nor felt, though they can affect photographic plates or operate electrical devices. Most sources of light require to be at a very high temperature before they become luminous, for example, an incandescent mantle of a gas burner, and then only a small portion of the radiation is light, most of it being in the form of heat. A few cases of ' cold ' light are known, but this phenomenon, known as **phosphorescence**, is produced by certain insects, such as the beetle commonly called a glow-worm, and by the minute marine organism called *Noctiluca*, which causes the phosphorescence of the sea. Another example is afforded by the cool burning of certain gaseous compounds of phosphorus due to the decomposition of organic matter. The glow called

Will-o'-the-wisp, seen above marshy places, and the light emitted by bad fish originate in this way.

Light itself is a kind of wave motion travelling at great speed through the ether of space. One of the most commonly known examples of wave motion is the formation of ripples on water when a stone is thrown into a pond. These ripples proceed outwards in horizontal circles away from the place where the stone enters the water, and give the impression that the water itself is moving towards the edge of the pond. But this is not the case; *the wave form, or succession of crests and troughs, is all that travels to the pond's edge*, the water itself merely moving up and down, as is shown by floating objects, such as pieces of wood. Waves on the sea are similar, though it must be realised that a sloping shore causes the up and down motion to be partly translated to a forward and backward movement. In deeper water, where this disturbing factor is absent, the water merely rises and falls, each particle moving up and down slightly later than the preceding particle, so that the wave motion takes a certain time in traversing a definite distance. Ocean currents and tides cause a movement of the whole body of water independently of wave motion.

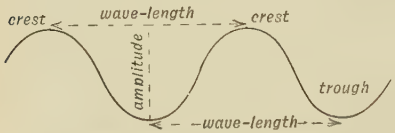


FIG. 192.—DIAGRAM REPRESENTING WAVE-LENGTH AND AMPLITUDE.

Though wave motion in water is large, slow, and rather complicated, it may serve to illustrate certain facts concerning wave motion in general, whether it occurs in ordinary matter, such as water and rocks (earthquakes, Chapter IV), or in the finer universal medium called ether, which extends through all ordinary matter and all apparently empty spaces. If the air is pumped out of a glass vessel, light can still pass through it because the ether is still there. Continuity is a characteristic feature of the ether, whereas ordinary matter is discontinuous, even a lump of iron or stone being composed of particles separated by innumerable minute spaces.

The waves of the sea appear as ridges or crests separated by intervening troughs. The horizontal distance between one

crest and the next is called the **wave-length,** which in this case may be three or four up to hundreds of feet (Fig. 192). The actual vertical distance through which the water rises and falls is known as **amplitude.** The horizontal distance traversed by the wave motion itself in one second is called the **velocity,** which in the case of water is very small, but *in the case of ether waves is very large, about* 186,326 *miles.* All ether waves, whether those we call light, or others which are known as electro-magnetic waves, travel at this great speed.

When we study sound, we shall find that there are *longitudinal* waves in which particles of air move forwards and backwards, but in those we are now considering the up and down motion is *transverse* or at right angles to the direction in which the wave motion as a whole travels. In some ether waves the wave lengths are exceedingly minute, merely a small fraction of one millionth of an inch, some such waves being those popularly termed **X-Rays,** also called **Röntgen** rays, after the man of science who discovered and named them.

The term ' ray ' is often used to denote a wave motion which radiates or spreads rapidly from a source of origin. Thus we have rays of sunlight, radiant heat, ultra-violet rays used in medical practice, and so on. Light waves are those transverse motions of the ether which produce the sensation called sight, when they affect the sensitive nerves of the eye. The wave-lengths of these particular waves vary from about 16-millionths to about 30-millionths of an inch, and all the other ether waves of larger or smaller wave-lengths are not perceived by means of sight, though some of them can be felt as heat, others can affect photographic plates, and still others can produce electric currents in the aerial of a wireless receiving station.

The waves used in wireless telephony are very long, usually hundreds of yards in length, and in this they differ considerably from the shorter waves producing light. But they travel through space at the same rate, 186,326 miles per second. It follows from this that there is a very much greater number of oscillations per second in the case of light waves than there is in the case of wireless waves, for it takes far more short waves than long waves to span 186,326 miles. The number of waves or

oscillations per second is known as the **frequency**, and the smaller the wave-length the greater the frequency. Even in the case of the longer light waves which produce red light, there are considerably more than 7000 million oscillations per second, violet light has about double this number, and the waves of other colours have intermediate frequencies. Even with much longer wireless waves the frequency is still great. Though the wave-length of the London wireless broadcasting station, 2LO, is 361·4 metres, about 2½ million of such oscillations occur in one second.

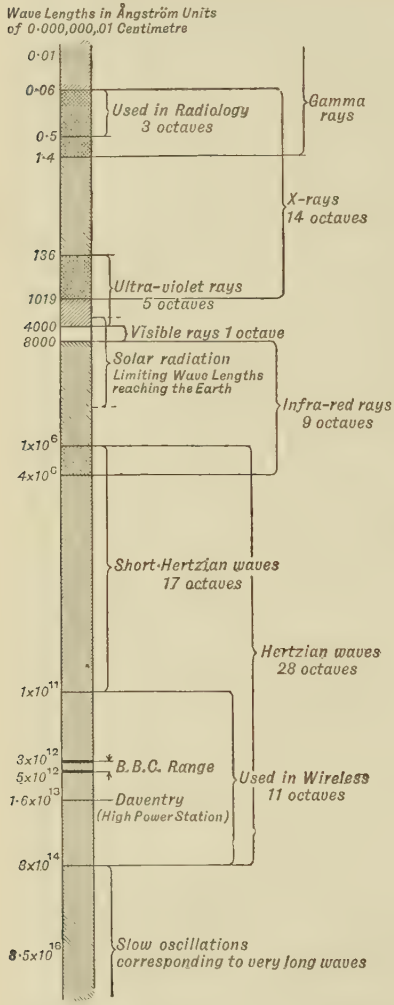


FIG. 193.—THE 'GAMUT' OF ETHER WAVES.

ADAPTED FROM A CHART PREPARED FOR THE ROYAL SOCIETY EXHIBIT AT WEMBLEY, 1925.

Sufficient has been said to show that light and wireless waves are both transverse oscillations of the ether and that they differ in wave-length and frequency.

If we refer again to the illustration afforded by waves in water, we can realise that just as the wall of a sea-front sends back or reflects water waves, so mirrors and other objects reflect light waves, mirrors of course doing this better than other things. But the analogy between motions in water and those in the ether

must not be carried too far. Waves in water are disturbances more or less confined to the surface layers, and the motion spreads in a horizontal direction only. Ether waves, whether those of light or others of different wave-length, radiate outwards in all directions through the space surrounding the source of origin, unless, of course, an object in the path of some rays obstruct their passage. When unimpeded, the advancing wave front is somewhat similar to a very rapidly expanding spherical shell, if one is permitted to make an analogy between spaces traversed by ether vibration and the forms assumed by ordinary matter.

In any region shielded from light rays by an object there will be a shadow of the object. This fact affords valuable proof concerning the roughly spherical shape of the earth, since its shadow on the moon is always circular. Eclipses have been described in Chapter II.

The relation between the form of the shadow and the shape of the object depends upon the fact that light rays proceed in straight lines, or at any rate in what appears to us to be straight lines. As **Einstein** has shown, such conceptions as straight

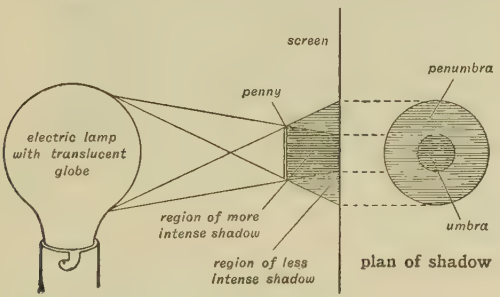


FIG. 194.

WHEN AN OBJECT IS SMALL COMPARED WITH THE SOURCE OF LIGHT, AND WHEN A SCREEN IS SUITABLY PLACED, THE SHADOW CONSISTS OF UMBRA AND PENUMBRA.

lines are *relative* and not absolute, even rays of light from distant stars being slightly bent aside by the influence of the sun. The character, *i.e.* not shape but intensity of a shadow, is mainly determined by the size and form of the source of light. If the source is a mere point, an object casts on a screen a shadow which

is uniformly dark. When the luminous source is large, such as the sun, the shadow of an object will generally consist of a darker portion or **umbra**, due to the complete obstruction of all rays, and a less intense portion or **penumbra** due to the obstruction of some, but not all of the rays, as the illustration shows (Fig. 194). Any object which effectively prevents the passage of light rays through it is said to be **opaque.** Most common materials—wood, iron, stone, etc.—afford examples. A substance such as clear glass which permits light to pass so that objects are seen clearly through it is described as **transparent,** but if only some of the light gets through so that clear vision is not possible, as in the case of ground glass or greased paper, then the object is said to be **translucent.**

COLOUR AND THE SPECTRUM

When light falls upon an opaque object it is either absorbed or reflected; most objects absorb some wave-lengths and reflect others. The energy of absorbed light is usually changed to heat. If nearly all the light from sunlight or other source of so-called white light is reflected the object appears white; if none of it is reflected, the object appears dull black. A black shiny object absorbs most of the light, but reflects a little, and the property we call lustre depends upon the character of the surface reflecting the light. Very smooth and highly polished surfaces reflect light so perfectly that images or pictures of things in front of them can be seen, and the reflecting surface is known as a **mirror.** More will be said about this later.

Light received from the sun is of a complex nature, being composed of waves of different lengths. That daylight is composed of several wave-lengths which separately give different colours can be shown fairly easily. In a darkened room a beam of sunlight is permitted to enter through a narrow slit in a shutter. This beam of light is passed through a triangular glass prism, and in going through it the light is bent aside or **refracted** (Fig. 195). On emerging from the glass into the air again the light is again bent farther in the same direction. A white screen is placed in the light which has emerged from the prism, and on this screen is

seen a continuous band of colours, ranging from red at one end to violet at the other. Between the red and the violet are successively arranged, orange, yellow, green, blue, and indigo, and one colour merges rather indistinctly into the next. This band of colour is known as the **spectrum** of sunlight, and it is clear that what we miscall white light is really a combination of different wave-lengths capable of producing different colours when the composite light is analysed or split up by means of a glass prism.

The discovery of this action of a prism on sunlight was one of the many achievements of Sir Isaac Newton, and we have a most

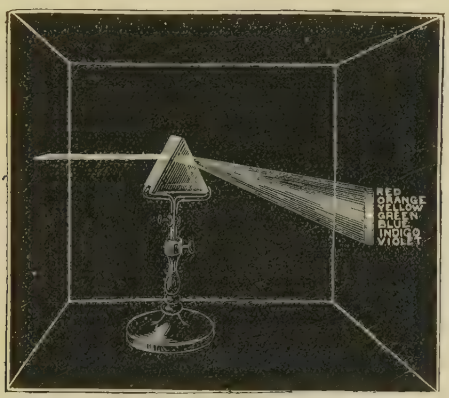


FIG. 195.—REFRACTION AND DISPERSION OF SO-CALLED 'WHITE' LIGHT BY A PRISM.

valuable practical application of this in the spectroscope, an instrument used extensively in astronomy and chemistry, as explained in Chapters I. and XXXVIII.

The colours of the spectrum are produced by light of different wave-lengths, the shorter violet waves being refracted by the glass more than the others, and the red waves are the least refracted of those perceived as light. As explained above, there are other still shorter waves beyond the violet end of the spectrum and longer ones beyond the red, but they are not visible. The separation of the various wave-lengths by a prism is called **dispersion.**

If an opaque object appears coloured, the colour is due to the reflection of only those wave-lengths which produce that particular colour. Thus a red rose is red because it reflects the red rays and absorbs the other rays of daylight. The colours of such objects are due to selective reflection and absorption. A man painting a motor car blue is covering the car with a substance which reflects only those wave-lengths which give the sensation called blue; all the other wave-lengths are absorbed. The numerous and varied tints seen in a garden of flowers or in fabrics are due to the reflection of various combinations of wave-lengths of the primary colours in the spectrum.

The production of colour in transparent substances, pieces of red glass for example, is rather different. In this case the glass allows red waves to pass through but not others; the glass also appears red when one looks *at* it and not through it, as it also reflects only red rays.

We have considered only cases in which the light employed is of the composite kind commonly called white, the standard example being daylight; but what happens if the source emits light having a wave-length corresponding to a certain colour only? When illumined by red light only, objects normally red in daylight are seen in their true colour; a blue object would appear nearly black in such red light because the object normally reflects only blue, and there are no waves of this length to be reflected. The normally blue object absorbs the red rays emitted by the source. For similar reasons, some coloured lamp shades produce curious effects; for example, a person's face appears ghastly when seen by light passing through a blue shade, since there is an absence of red and warm tints which produce the normal healthy appearance of the face.

We are now in a position to understand why the colours of fabrics, curtains, carpets, etc., usually appear in artificial light different from their normal appearance in daylight. The light emitted by electric lamps, gas flames, etc., does not contain the waves of various lengths in the same respective proportions as found in daylight. The longer red waves are present in greater proportion than in daylight, but on the other hand the proportion of blue waves is smaller. From this it follows that a red carpet

will reflect relatively more red rays by artificial light and will appear to be of a stronger red at night than in the day time, but a blue carpet is a more intense blue in day time than at night. The quality of other colours will be modified; for example, purple, which contains both red and blue, will appear to have a higher proportion of red when seen by artificial light.

Rectifying devices are often used to make the artificial light as much like daylight as possible. A daylight effect may be produced either by passing the artificial light through a glass bulb so coloured as to block out some of the red and add blue, or by placing a suitably coloured reflector above the lamp. Such a reflector will adjust the relative proportion of the wave-lengths by means of patches of various colours, chiefly blue, with smaller amounts of green and yellow. If a coloured fabric is to be matched accurately it is better to employ ordinary daylight rather than trust any type of ' daylight ' lamp.

ATMOSPHERIC COLOUR EFFECTS

The sunlight which illumines the earth during the greater part of the day is composed of all wave-lengths from violet to red, but at sunrise and sunset certain colours, chiefly yellows and reds, are seen because the wave-length producing the other colours of the spectrum fail to reach us. Enormous numbers of very minute particles of dust and water vapour scatter or reflect the blue vibrations, but colours due to larger wave-lengths, the reds and yellows, pass on, since the dust and other particles are not large enough to reflect them. A dust particle cannot reflect a wave-length greater than the size of the particle itself. At sunrise and sunset the red and yellow rays reach us, the blue rays do not, the great thickness of air, and consequently the greater number of dust particles, intercepting the light at such times being decisive factors. Snow-clad peaks of mountain ranges illumined by the red rays of dawn or sunset is one of the grandest sights in the world. Remarkably vivid colour effects are sometimes due to the great increase in the quantity of dust in the air by volcanic explosions, such as that of Krakatoa in the year 1883, when a series of extraordinarily beautiful sunsets were seen.

The sun when seen through a thin mist of water vapour appears red because the shorter wave-lengths are reflected away from us. The blue colour of a clear sky is also caused by the reflection of blue wave-lengths, but in this case these waves reach us because the reflecting particles are above and not roughly between us and the sun, as they are at sunset or sunrise. If there were no particles to reflect the rays the sky would appear black. The colour of clouds depends upon the relative propor-

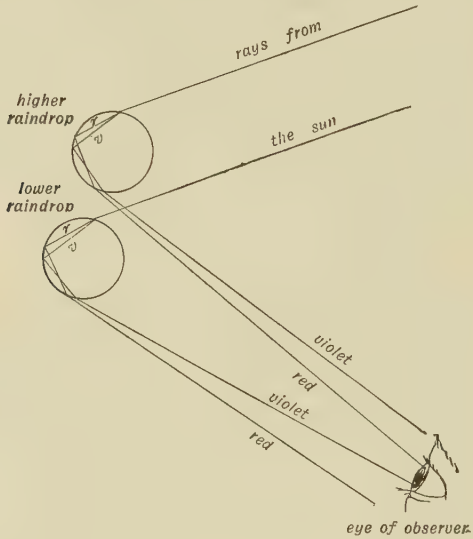


FIG. 196.—DIAGRAM ILLUSTRATING THE ACTION OF RAINDROPS IN FORMING A PRIMARY RAINBOW.

tions of the various wave-lengths absorbed or reflected, and this depends upon the size of particles forming the cloud.

These effects are due to reflection, but a **rainbow** is produced by combined reflection, refraction, and dispersion, drops of rain acting as if they were so many glass prisms splitting up the composite sunlight which enters them (Fig. 196). In order that a rainbow shall be seen certain conditions must be fulfilled. The sun must be above or behind the observer and a falling shower of rain must be in front of him. As a ray of light enters a drop of

water refraction and dispersion take place, the light being split up and the different wave-lengths separated by unequal refraction. On reaching the back of the drop of water reflection occurs, the waves being sent forward, and on emerging from the drop the dispersion of the colours is increased. The reflection by the back of the raindrop reverses the order of the colours, so that violet occurs on the inner side of the rainbow, and red on the outside. Since the positions of all those drops which can produce a visible effect on a given observer are situated along arcs of circles, the rainbow has the characteristic curved form. Sometimes another outer and fainter bow is seen, and in this the order of colours is the reverse of that in the primary bow. On a bright sunny day a small rainbow can be produced by means of a garden hose, provided the falling shower, sun, and observer are all in the correct relative positions.

CHAPTER XXIII

ILLUMINATION

The amount of light received by an object from a luminous source depends upon three things—the illuminating power of the source, the size of the object illumined, and the distance separating the source from the object. Generally, the degree of luminosity of a source largely results from its temperature; the higher the temperature the greater the amount of light emitted by unit area, and, of course, the greater the size of the luminous object the larger the total amount of light radiated. Though the earth is 93,000,000 miles distant from the sun, the light we receive is considerable because the sun's temperature is enormously high (see Chapter I) and its size is great.

The good illumination received from an electric arc lamp is due to the high temperature of the arc, about 3500°; the size of the arc itself is small. The temperature of an ordinary electric lamp must be sufficiently high if the filament is to be white hot and not merely red hot. On the other hand, a luminous bunsen flame is cooler than a non-luminous flame, so that luminosity does not always increase with temperature.

The relation between the total amount of light received by an object and its size is quite simple; if there are two things at equal distances from the same source of light, but one has four times as big a surface as the other, it will receive four times as much light, provided that the angle at which the light rays strike the two objects is the same.

The relation between the distance of the source and the amount of light received by the object is not quite so simple, as an easy experiment shows. A piece of cardboard, or preferably of sheet metal, having a small hole pierced in it,

is placed in front of a lamp (Fig. 197). Light passes through the hole and proceeds forwards in straight lines which diverge wider apart as they extend farther. Now a second piece of cardboard having a square hole about one square inch cut in it is placed in the pathway of these rays at a suitable distance from the first piece of cardboard. If this distance is two inches, a third cardboard is placed at a distance of four inches from the first piece. On this screen an area of four square inches is illumined by light which passes through a hole of one square inch at half the distance from the source. It is obvious that *at double the distance the same light rays will illumine an area four times as large as that illumined by them at the original distance.* This being the case, the intensity of light or the amount received per square inch at this greater distance is only $\frac{1}{4}$ of that received at the other position half the distance from the source. In the case of light spreading in all directions this relation is true for all distances and affords another example of the law of inverse squares. *The intensity of illumination varies inversely as the square of the distance separating the source from the object.* In scientific work this intensity of illumination is measured by the amount of light which falls on a square centimetre of surface placed at right angles to the direction along which the rays proceed.

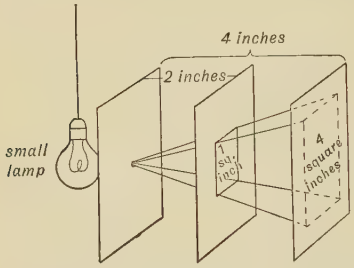


FIG. 197.—A METHOD OF ILLUSTRATING THE LAW OF INVERSE SQUARES.

The inverse square law is of great use since it enables us to make careful comparisons of the respective illuminating powers of various sources of light.

If actual measurements are to be made, some standard source of light is necessary, and formerly, when candles were more important than they are now, the illuminating powers of lamps, etc., were expressed in terms of candle power, or the light emitted by a **standard candle.** Such a candle was composed of sper-

maceti wax, of which 120 grains were consumed in one hour, and six candles weighed one pound. At the present time a **standard pentane lamp** burning pentane, a product derived from paraffin, is employed. Properly adjusted, such a lamp is equal to ten standard candles, and we still describe lamps as being of so many candle power.

When either candle or lamp is used as a standard, the illuminating power of any other source of light is measured by a process based upon the law of inverse squares, and the instrument by which the measurement is made is called a **photometer**. Some of these instruments yield much more accurate results than others. One of the older types, not much used to-day but nevertheless of considerable interest, is known as **Rumford's shadow photometer** since the distances of various sources of light are adjusted so that the shadows of a rod appear of equal intensity. A vertical rod just in front of a white screen casts a shadow upon it when a standard candle is placed at a convenient distance from the screen. The lamp, the candle power of which it is desired to measure, is placed so that the shadow formed appears equally dark as the other one, hence the two sources of light, candle and lamp, are then illuminating equally the portions of the screen around the shadows, and the relative powers of the lights are in proportion to the squares of the respective distances. If the candle is two feet from the screen and the distance of the lamp is four feet, the illuminating powers are represented respectively by the numbers 4 and 16, and the lamp is said to be of four candle power. The shadow method is liable to inaccuracy since it is not easy to say exactly when the shadows are equally intense, and people differ in their powers of observation.

More accurate results can be obtained from the use of **Joly's photometer**, which consists of two small slabs of paraffin wax equal in thickness and separated by a sheet of tinfoil (Fig. 198). The standard light is placed at a convenient distance in front of one piece of wax, and the light to be tested is placed in front of

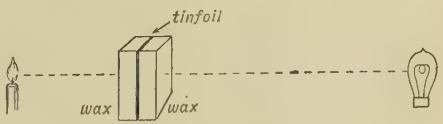


FIG. 198.—JOLY'S PHOTOMETER.

the other and its distance varied until the two pieces of wax viewed from the side appear equally illumined. As before, the relative powers of the sources of light are proportional to the square of their respective distances. It must be realised that *the power of a source is one thing, and the illumination at a place is another*, the latter varying *inversely* with the square of the distance from the source.

Another interesting though very simple type of apparatus is **Bunsen's grease spot photometer.** If two sources of light are placed one on either side of a sheet of paper containing a small greased area, the grease spot becomes invisible when viewed from either side if the two sources are at such distances that the illumination of both sides of the paper is equal.

This is the principle of the **Benjamin lightmeter** employed for measuring the degree of illumination in class rooms, workshops, etc. This consists of a long box containing a lamp near one end, and rays from this lamp strike a translucent screen above at different angles and at different distances. Consequently the illumination due to the lamp is different at different parts of this screen, being greatest just above the lamp. A sliding cover having a translucent spot is moved along the screen until the spot becomes invisible ; the external illumination is then equal to that of the lamp at the place where the translucent spot is situated. If the intensity of illumination due to the lamp at different positions along the screen has been determined and calibrated previously, the degree of external illumination can be read directly from a scale. Practical units of light intensity are required, and those employed are known as **foot candles.** *One foot candle is the degree of illumination received by a vertical white screen placed at a horizontal distance of one foot from a standard candle.*

According to the law of inverse squares, 100 standard candles or one 100 candle-power lamp produces an illumination of one foot candle at a distance of 10 feet. An electric lamp of this power is commonly used in sitting rooms of average size, but of course the illumination on the wall will be one foot candle only when the wall is 10 feet from the lamp. Lamps of the same candle power used in rooms of equal size produce different

degrees of illumination because of variation in the colour and surface of walls, furniture, and effects, since different substances absorb and reflect varying quantities of light. Dark wallpapers absorb more than pale ones, consequently a source of light must

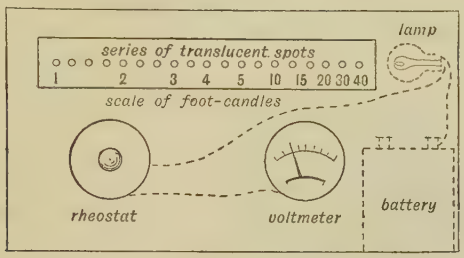


FIG. 199.—PLAN OF A LIGHTMETER.
WHEN THE VOLTAGE, HENCE THE LAMP, IS PROPERLY ADJUSTED, THE ILLUMINATION IS READ DIRECTLY FROM THE SCALE.

be of a higher candle power to produce good illumination in a room having a dark colour scheme than that required for a room brightly furnished and decorated. The following examples give some idea concerning the proportion of light reflected by wall-papers, etc.:

Ordinary white paper reflects about			80 %	of	incident	light.
Clean white wood	,,	,,	50 %	,,	,,	,,
Blue paper	,,	,,	25 %	,,	,,	,,
Brown paper	,,	,,	14 %	,,	,,	,,
Black cloth	,,	,,	1·5 %	,,	,,	,,

The degree of illumination required depends upon the purpose for which the light is used, some occupations requiring more light than others, and the figures given below may be considered normal for the various purposes quoted :

watchmakers require 12 or more foot candles ;
for sewing dark material from 8 to 10 foot candles ;
draftsmen, from 6 to 8 foot candles ;
shops (clothing) from 4 to 7 candles ;
school classrooms from 2 to 3 foot candles ;
ordinary sitting rooms require about 2 foot candles ;
churches and assembly halls require 1 to 1·5 foot candles.

It is possible to read printed matter of average size with an illumination of only one quarter of a foot candle, but more light than this is desirable if eye strain is to be avoided.

We must distinguish between good diffused light and **glare**, the latter being caused by a *high degree of luminosity per unit area of the source of light*. If the same amount of light from a motor head lamp could be radiated from a larger surface the glare would be reduced. Alabaster bowls often placed below sitting room electric lamps diffuse the light and cause much of it to be reflected by the ceiling, thus producing a 'soft' effect practically free from glare. The filament of the lamp is of small area yet emits light of a hundred candle power, consequently glare results unless the lamp is screened.

FIG. 200.—A LUMINOUS BUOY USING ACETYLENE.
(By courtesy of Messrs. Chance Bros.)

In good illumination the light should be 'white,' that is, it should be composed of the various colour wave-lengths in the same proportions as found in sunlight. Most artificial lights do not contain the colours in correct proportions, hence the use of compensating devices mentioned in the previous chapter.

In towns electric light and coal gas are used for lighting purposes. With modern burners the value of coal gas depends upon its heating power, light being produced by a mantle rendered white hot by the heat of the flame. In addition to the use of oil, country house lighting may now be effected by the use of **electricity, petrol-air gas,** or **acetylene.** The machinery

necessary for the production of electric light consists of a dynamo, a petrol motor to work it, and some accumulators (Chapters XXVII and XXVIII). Petrol-air gas consists of air mixed with about 5 per cent. of petrol vapour, such a mixture forming a safe non-explosive and non-asphyxiating substance. As in the case of coal gas, incandescent mantles are employed. The generating apparatus contains a carburettor for vaporising the petrol, means of mixing it with air in the correct proportion, and a container for storing the mixture under the required pressure.

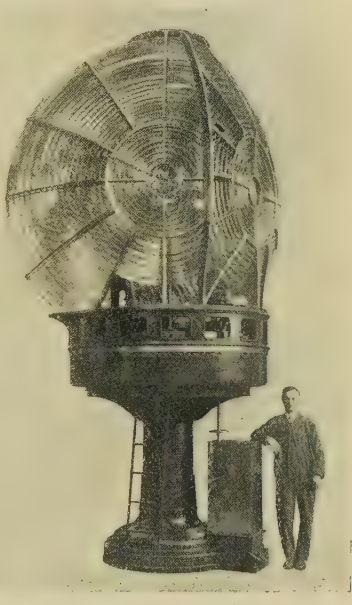


FIG. 201.—LIGHT-HOUSE APPARATUS.
(By courtesy of Messrs. Chance Bros.)
See also Chapter XXV.

Acetylene can be generated by letting water drip at a definite rate on **calcium carbide**, as in the acetylene lamps used on bicycles and motor-cycles or it can be obtained dissolved in a liquid hydrocarbon called **acetone** contained in large steel cylinders. At normal atmospheric pressure acetone dissolves about 25 times its own volume of acetylene. In this form it is much used for other purposes, such as luminous buoys at sea and oxy-acetylene welding. Acetylene burners do not require mantles, and the light obtained approximates in character to that of sunlight. For country house lighting, electricity is the most expensive, and acetylene is the least costly so far as initial outlay is concerned. In a complete installation for 20 lights of the usual candle power, electricity would cost about £142, petrol-air gas about £86, and acetylene £60.

For certain purposes, lights of thousands or even millions of

candle power are required. In optical projection lanterns, either electric arc lamps or the light from an incandescent cylinder of lime is employed, in the latter the heat necessary to render the lime luminous being obtained from the combustion of coal gas in oxygen, the latter being stored under pressure in a steel cylinder. The electric arc is used in searchlights and in the larger lighthouses, such as that of St. Catherine's in the Isle of Wight, which has a candle power of several millions. Smaller lighthouses, harbour lights, etc., make use of vaporized oil, which renders a mantle burner incandescent. For outdoor work as performed on railway tracks, and for certain naval and military purposes, a light which remains steady in spite of wind and rain is required. Such illumination is obtained from a self-contained and portable apparatus known as the **Wells Light** (Fig. 202). In this, oil spray blown horizontally gives a perfectly steady light varying in intensity from 500 to 3000 candle power according to the size of apparatus.

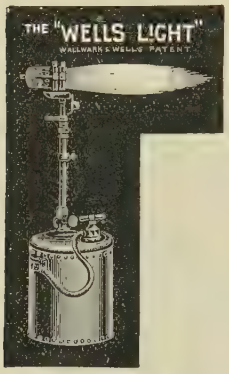


FIG. 202.—A LIGHT NOT INFLUENCED BY WIND AND RAIN.
(By courtesy of Messrs. Wells & Co. Ltd.)

CHAPTER XXIV

REFLECTION AND MIRRORS

A mirror or **looking-glass** is a most useful article, enabling one to see things which would otherwise be invisible. For example, how can a man see to shave himself, or a dentist examine teeth properly, without the aid of a suitable form of mirror? A looking-glass functions as it does because it is a good reflector of light.

The light which falls upon an object is partly reflected and partly absorbed. A piece of white paper reflects most of the light striking it, but a piece of dull black paper absorbs nearly all light reaching it. Black letters on the page of a book absorb light, while the surrounding white ground reflects it, hence the contrast which makes reading possible. Though a piece of white paper reflects a good deal of light it does this in a very irregular manner, the rays which strike the paper being sent back in general disorder, some proceeding this way, some that way, and so on (Fig. 203). If a lighted candle is held in front of such a piece of paper, a picture or **image** of the candle flame is not seen as would be the case if it were held in front of a mirror. The rays reflected by the paper are too disorderly for an image to be formed, but

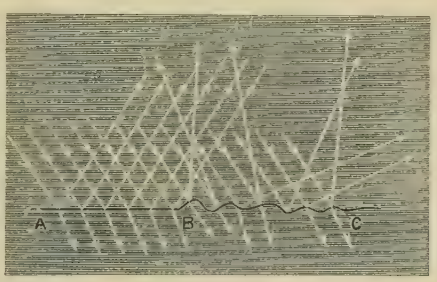


FIG. 203.—REGULAR REFLECTION OF LIGHT (BETWEEN A AND B) AND IRREGULAR REFLECTION (BETWEEN B AND C).

THE REFLECTING MATERIAL BEING IN THIS CASE A BLOCK OF GLASS, MANY RAYS PASS INTO THE GLASS AND ARE REFRACTED.

in the case of a mirror the rays are perfectly or accurately sent back, so that they appear to reconstruct a picture of the object which sends them to the mirror. The degree of perfection with which light rays are reflected evidently depends upon the smoothness of the reflecting surface. A rather crude analogy may help to make this point clear. If a tennis ball is thrown at an angle of 45° against a smooth plaster wall, it will rebound, making another angle of 45°, but if it is similarly thrown against a rough wall composed of variously shaped flints, the angle at which it rebounds depends upon the way in which it actually strikes one of the pieces of flint. The piece of white paper is somewhat similar to this flint wall; its surface is irregular though on a microscopic scale, and the light rays which fall upon it are scattered or **diffused** in all directions. The surface of the mirror is similar to that of the plaster wall but, of course, on a microscopic scale.

It takes an enormous number of light rays to form an image, and all of them must be reflected accurately; if many are sent in the wrong direction the image is not produced. It follows from this that only very smooth surfaces, such as those of highly polished metal, glass, mercury, and water, are capable of reflecting light so that images are formed. In reflection, perfect or imperfect, each ray of light is returned at an angle equal to that at which it strikes a spot on the reflecting surface, but in imperfect reflection these spots are facing all directions because the reflecting surface is uneven, and the rays are scattered instead of coming back properly to build up an image.

The formation of images or pictures by mirrors results from the fact that any ray of light is reflected at an angle equal to that at which it strikes a reflecting surface. It is as well to explain this law of reflection a little further. A ray of light striking a mirror at a certain point is said to be *incident* at that point, and is called the **incident ray.** After reflection it is known as the **reflected ray.** If a line is drawn at right angles to the mirror and touching it at the same point as the incident ray, such a line is called a **normal** and in practice this line is used to describe the angles of incidence and reflection. *Thus the angle made by the incident ray with the normal is called the angle of incidence, and*

that made by the reflected ray and the normal is called the angle of reflection, and both of these angles lie in the same plane. The law of reflection is usually stated by saying that **the angle of incidence equals the angle of reflection.** A practical application of the rule is afforded by the case of a flat mirror placed at a corner where two passages form a right-angled bend. In order that a person in one passage may see along the other the mirror must be placed at an angle of 45° to each passage (Fig. 204).

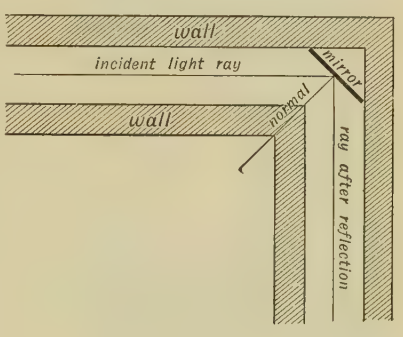


FIG. 204.—A PRACTICAL APPLICATION OF THE LAW OF REFLECTION.

THE MIRROR PLACED AT 45° TO EACH OF THE TWO CORRIDORS ENABLES A PERSON IN ONE CORRIDOR TO SEE ACCURATELY ALONG THE OTHER.

The image of a small object, say a pin placed in front of a plane or flat mirror, can be found experimentally and proved geometrically by using the law of reflection. A pin (P) is placed two inches in front of a flat mirror (Fig. 205). Now the pin reflects daylight which falls upon it, and though it is not self luminous it

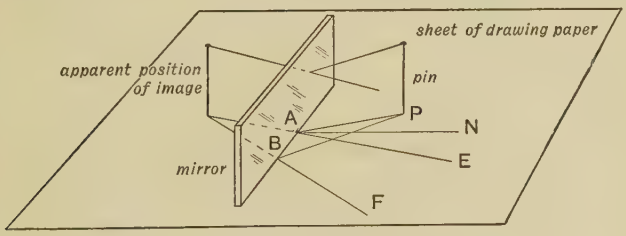


FIG. 205.—THE FORMATION OF A VIRTUAL IMAGE OF AN OBJECT PLACED IN FRONT OF A PLANE MIRROR.

may be regarded as a source of *borrowed* light. It is important to remember this, as all non-luminous bodies, including ourselves, behave in this way, and by means of the borrowed light they can send rays by which they are seen. Consider any ray PA sent

by the pin to the mirror. Draw a normal NA and make the angle NAE equal to the angle NAP. Then AE is the path of the reflected ray, which appears to come from a position behind the mirror. Similarly, consider another ray PB, which after reflection comes back along the line BF and also appears to come from the same position. The paths of any other rays may be traced, and it will be found that after reflection they all appear to come from the position I where an image of the pin seems to be.

Though the picture in our minds is real enough, actually the image is not there since the light rays cannot pass through the mirror, and an image of this sort is said to be **virtual.** Some curved mirrors and lenses can actually bring rays of light together so that they construct a **real** image, but with flat mirrors the images are always virtual; they merely appear to be there.

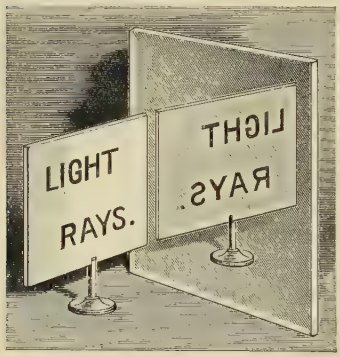


FIG. 206.—AN EXAMPLE OF LATERAL INVERSION.

Another deception must be observed. If you stand in front of a plane mirror you see the image of a person who seems at first sight to be quite like yourself. But that person's right arm is the image of your left arm, in fact the whole of his right side is the reflection of your left side and *vice versa*. This phenomenon is called **lateral inversion** and explains why the writing on blotting paper can be read if it is held before a mirror (Fig. 206). The setting of printers' type can be tested in the same way.

Two other points in connection with these virtual images formed by *flat* mirrors must be realised; *the image always appears to be the same distance behind the mirror as the object is in front of it, and is apparently the same size as that of the object.* Most mirrors used in domestic life are made of glass backed by *mercury* (or by silver in some modern processes), and

if the glass is thick, several images of a lighted match may be seen if it is held quite close to the mirror; this is due to repeated reflection between the inside surface of the front face of the glass and the silvered back of the mirror (Fig. 207).

FIG. 207.—MULTIPLE IMAGES OF A CANDLE FLAME FORMED BY A THICK MIRROR.

Plane mirrors are essentially articles of domestic use, but another useful application called a **periscope** consists of flat mirrors so arranged that one is able to see objects the other side of a wall or trench. Two adjustable plane mirrors are placed within a tube, one facing the lower aperture in front of the observer, the other near an upper aperture facing the direction from which the desired view is to be obtained (Fig. 208). When the mirrors are adjusted to the correct angle the observer obtains a view of the country beyond the trench without exposing himself.

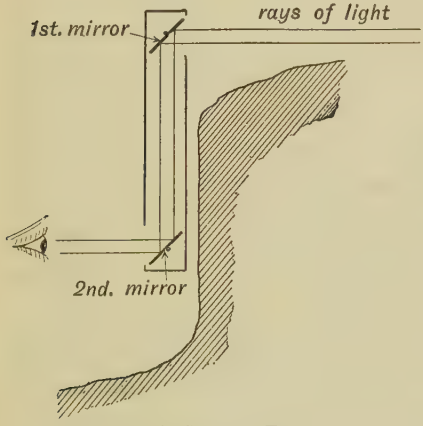


FIG. 208.—A SIMPLE REFLECTING PERISCOPE.

This simple type of periscope is different from the more complicated kind employing a prism which is used on submarines. The action of this refracting periscope is considered later.

Interesting experiments can be performed by placing a pin between two parallel mirrors or between two plane mirrors inclined

at various angles. With parallel mirrors an infinite number of images is possible theoretically. The number with two mirrors at an angle depends upon the size of the angle.

REFLECTING TELESCOPES, SEARCHLIGHTS, AND OTHER DEVICES

What happens when light falls upon a mirror that is not flat but curved? Much depends upon the kind of curvature possessed by the mirror, which may be spherical, that is, part of a sphere, or may be curved without being spherical, an example being an ordinary tablespoon. Many reflectors of considerable practical value are in curved forms called *parabolas*, but at first we must consider the case of spherical mirrors. If the reflecting surface is on the outside of the sphere we have a *convex* mirror, but if the reflecting surface is on the inside the mirror is said to be *concave*.

A motor car is provided with a **convex** mirror placed near the driver, so that he can see a reduced but accurate picture of the road immediately behind him. Since the image is reduced, a small mirror gives a picture showing all objects on a considerable width and length of road. A plane mirror to give satisfactory results would have to be far too large to be convenient.

Now, how is this reduced picture formed by the convex mirror? Consider the case of a single small object, say a pin, placed in front of such a mirror. An image of the pin is seen as if it were behind the mirror, and this image is *virtual, as are all other images formed by convex mirrors.* But, unlike the image formed by a plane mirror, it is *smaller* than the object itself and its apparent distance behind the convex mirror is not equal to the distance the object is in front of the mirror. Another fact must be noted. The image is erect, or the right way up; it is not inverted as are some. These facts can be summarised by saying that *all images formed by convex mirrors are virtual, erect, and reduced in size*—a very useful combination of features.

In order to understand how images are formed by convex or other curved mirrors, we must trace the courses of a few of the light rays proceeding from the object to the mirror. A pin is

placed about two inches in front of a convex mirror as shown in the diagram (Fig. 209). As explained above, rays of daylight are reflected by the pin in all directions. Select one of these rays, x, which happens to strike the curved mirror at right angles to the surface. By the law of reflection, this ray is reflected back along the same line, and appears to come from the **centre of curvature** C, or centre of the sphere of which the mirror is a portion. The point p at which this ray strikes the mirror at right angles is called the **pole** of the mirror, and is used in calculations as a starting point to measure distances from the mirror.

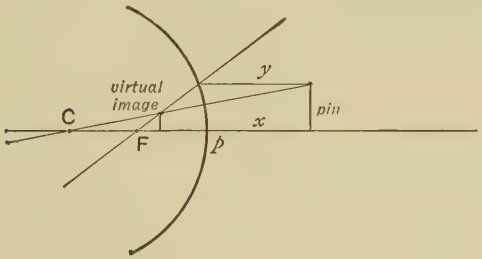


FIG. 209.—THE FORMATION OF A REDUCED VIRTUAL IMAGE BY A CONVEX MIRROR.

Now consider any other ray, y, parallel with the first ray, x. This ray, y, strikes the mirror obliquely, but also conforms to the law of reflection ; it is reflected at an angle equal to that at which it is incident, and appears to come from a point F behind the mirror. *All other rays which are parallel with x and y will also be reflected so that they all appear to come from the point* F, *which is therefore called the* **principal focus** of the mirror. The path of a third ray must be traced if the position and size of the image are to be ascertained. Suppose we select another, which, proceeding from the top end of the pin, is normal to the surface of the mirror. As in the case of x, this ray after reflection appears to come from the centre of curvature, C, and will cut across the apparent path of ray y behind the mirror. This point of intersection marks the upper end of the reduced image of the pin, since the rays from the upper end of the pin appear to come from that point. Thus it can be shown geometrically

that the image is not only reduced in size, but upright, and at a smaller distance from the pole of the mirror than the pin itself is.

One or two other facts concerning curved mirrors, whether convex or concave, should be noted here. The ray we chose first, x, happens to proceed along a line known as the **optical axis** of the mirror, along which are situated the principal focus F and the centre of curvature C. The distance between p and F is called the **focal length**, f, of the mirror, and f is equal to half the radius of curvature. There is a definite relation between the distance of the image, the distance of the object, and the focal length ; and if the symbols v, u, and f are respectively used for these three quantities, their relation is expressed by the equation

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}.$$

Note that v, u, and f are all measured in the same units, centimetres or inches.

This formula is true for all spherical mirrors, but when making calculations all distances must be measured from p, the pole of the mirror, and the correct sign, positive or negative, must be employed for each quantity. *Distances measured from the pole towards the source of light are positive, while those measured in the same direction as the incident light are negative.* Hence the focal length f of a convex mirror is always negative. An example will illustrate the use of the equation in calculations.

An object is placed 24 centimetres in front of a convex mirror of 12 centimetres focal length. Find the position of the image.

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f},$$

and in this example $u=24$ and $f=12$. Hence we have

$$\frac{1}{v}+\frac{1}{24}=-\frac{1}{12}, \quad \frac{1}{v}=-\frac{1}{8};$$

therefore $$v=-8.$$

The image appears to be eight centimetres behind the mirror, the minus sign indicating that the position is virtual. *The ratio of the length v to that of u gives the relative size of the*

image. Thus, in this case, v is to u as 8 is to 24, therefore the image is $\frac{1}{3}$ the length of the object.

Now let us see what sort of an image can be obtained by the use of a concave mirror. A useful form of such mirror is known as a **shaving-glass**, but a person has to place himself quite close to it to obtain an enlarged image of his face. If he moves backwards the image disappears. Suppose we consider the case of a pin placed quite close to a concave mirror (Fig. 210).

There is a principal focus, a centre of curvature, and a pole of the mirror as before, also the focal length is half the radius of curvature, but *positive* this time. Let the pin be placed at a distance less than the focal length. As before, draw three rays,

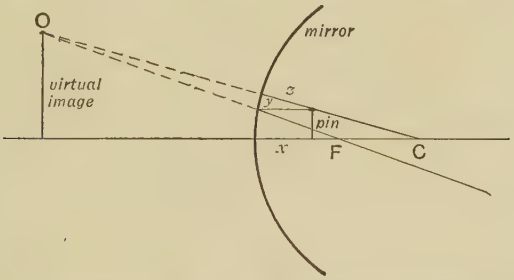


FIG. 210.—THE FORMATION OF A MAGNIFIED VIRTUAL IMAGE BY A CONCAVE MIRROR, FOR EXAMPLE, A SHAVING GLASS.

one, x, passing along the optical axis and being reflected along the same line. A second ray, y, is parallel with x and after reflection will pass through the principal focus, F, while z, which is normal to the mirror, is reflected through the centre of curvature. Now the rays y and z appear to meet at a point O behind the mirror, and the image is virtual, erect, and enlarged. *When an object is placed at a distance less than the focal length the concave mirror functions as a magnifying glass.* Try this with a tablespoon and a lighted match. Although the spoon is not spherical, somewhat similar results are obtained. Compare the image formed by the concave side with that obtained with the convex side.

When the pin is placed at a distance greater than the focal length, but less than the radius of curvature, very different results

are obtained (Fig. 211). The rays proceed to the mirror as before, but it will be noticed that *y* and *z* this time actually meet at a point O in front of the mirror and that the image occurs in front, and is *real*; *it can be caught on a screen of tissue paper held in the correct place.* The rays actually build up an image which is not merely virtual. This image is also *enlarged but inverted.*

An interesting feature in connection with real images formed by a concave mirror is that the positions of the object and image are interchangeable and are called **conjugate foci.** If you place the object where the image is, then the image will be formed where the object was previously. It follows from this that if an object

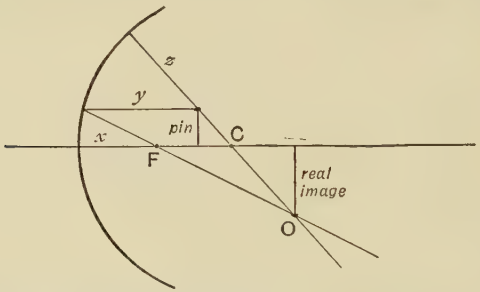


FIG. 211.—THE FORMATION OF A REAL IMAGE BY A CONCAVE MIRROR.

is placed beyond the centre of curvature of a concave mirror, a reduced inverted real image will be formed at a position between the centre and the principal focus. If you possess a concave mirror, verify this for yourself by placing the mirror on a table in such a way that it receives rays from an electric or other light some distance away. When you look at the mirror with your eye in the necessary position you will see a small inverted image of the light floating in the air some inches in front of the mirror. This image can be seen without the use of a screen, and you will appreciate the fact that it is real.

In a **reflecting telescope** the ' object glass ' is a large concave mirror which forms an inverted real image of the far distant object, say a star, which is, of course, an immense distance beyond the centre of curvature. In this case the image will be

formed at the principal focus, and an ordinary magnifying lens or eye-piece can then be used to give an enlarged reproduction of the real image.

Owing to the difficulty of making very large glass lenses, modern tendencies are in favour of the large reflector. The larger the aperture or objective of a telescope, whether a glass lens or a mirror, the more light can be grasped by it.

The formula $1/v + 1/u = 1/f$ can be used in calculations on concave mirrors provided the correct signs are employed. Thus, at what distance must an object be placed in front of a concave mirror of focal length 12 cm. in order to produce an image at a distance of 30 cm. ?

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}.$$

In this example,

$$\frac{1}{30} + \frac{1}{u} = \frac{1}{12};$$

therefore

$$\frac{1}{u} = \frac{1}{12} - \frac{1}{30},$$

$$\frac{1}{u} = \frac{1}{20},$$

$$u = 20.$$

The object must be placed 20 centimetres in front of the mirror. The image is real, inverted, and its size, determined by the ratio of v to u, is $1\frac{1}{2}$ times that of the object.

Certain kinds of curved mirrors are very useful in cases where a beam of light has to be projected a long way. A **searchlight** apparatus consists of a powerful electric arc lamp, behind which is a curved mirror which throws the light forwards in the form of a powerful beam capable of illuminating objects at a great distance.

We have seen that all rays parallel with the optical axis of a concave mirror pass through the principal focus, F, after they have been reflected. The process can be reversed by *putting a light at the principal focus* and obtaining by reflection a series of

parallel rays of light (Fig. 212). The more accurately parallel these rays are, the farther will they extend without spreading. The advantage of such a parallel beam of light in connection with *railway signal lamps* and searchlights is obvious. But a truly spherical mirror does not produce an accurately parallel beam owing to a defect termed **spherical aberration,** and to produce better results **parabolic** mirrors are used in place of spherical ones. A section through a parabolic mirror gives a curved line called a parabola, instead of an arc of a circle. Spherical aberration may be described as the inability of a spherical mirror to focus accurately at the principal focus all rays parallel with the optical axis, or conversely, the inability to produce a beam of exactly parallel rays when a light is placed in the position of the principal focus.

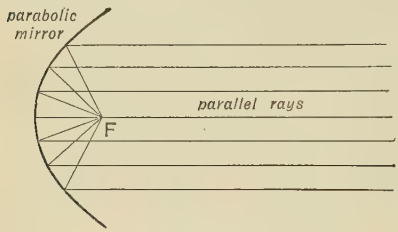


FIG. 212.—THE PRINCIPLE OF A SEARCHLIGHT.

A LIGHT PLACED AT THE PRINCIPAL FOCUS OF A PARABOLIC MIRROR WILL REFLECT A PARALLEL BEAM OF LIGHT.

Radiant heat and waves of sound can be similarly projected as parallel beams by concave reflectors and re-focussed again by a second mirror. The modern beam system of wireless wave-projection is analogous to the projection of parallel beams of light by a searchlight.

CHAPTER XXV

REFRACTION AND ITS PRACTICAL APPLICATIONS

When a ray of light leaves one transparent substance or **medium** and enters another, its direction is altered, and the ray is said to be **refracted.** The amount of this alteration or bending aside depends upon the relative densities of the two media and upon the wave-length of the light ray. The greater the difference in the densities of the two media the greater is the refractive effect. The composite or ' white ' light which leaves air and enters a triangular glass prism is all refracted or deviated to one side, but, as we have seen, the violet rays are more refracted than the longer red rays.

The direction in which the light proceeds after it has emerged from one medium into the other depends not only upon the relative densities of the media but also upon the angle at which the rays strike the surface separating the two media. In other words, the shape of a piece of glass or other transparent substance largely determines the direction in which the rays of light proceed after emergence.

This fact is of enormous practical importance. Window panes are composed of sheets of glass having two flat parallel surfaces, so that rays of light, although refracted in passing through the glass, emerge in directions parallel with those at which they entered the glass. Although each ray is slightly shifted to one side by its passage through the window pane, the object viewed, say a house, is seen in front of an observer, as it is in reality. If the window were composed of a wedge-shaped piece of glass wider at one edge than at the other, the house would appear to be shifted considerably to one side of its real position. In this case the object would be viewed through a flat

type of prism and not through a plate or *lamina*, having parallel faces. Dispersion of wave-lengths would also occur, giving a picture of the house with coloured edges. Irregularities in thickness or flaws in the window pane produce distortion, since the rays are there refracted irregularly.

Pieces of glass or other transparent media, such as rock crystal, having curved faces are called **lenses**, and the ways in which these react upon light are described later.

Refraction, due simply to the different densities of two media in contact along a uniformly flat surface, is well illustrated by rays emerging from a pool of water into the air. A stone at the bottom of the pool reflects rays of light, and as each *oblique* ray emerges from the water it is bent more obliquely (Fig. 213). The eye of an observer fails to perceive this alteration in direction to

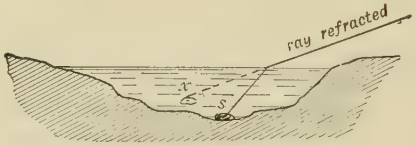


FIG. 213.—REFRACTION CAUSES A POOL TO APPEAR LESS DEEP THAN IT REALLY IS.

the rays ; he is deceived, and to him the stone appears to be in the position x, instead of in its real position s. Not only is the apparent position of the stone shifted to one side, but the water also appears less deep than it really is. If the stone is viewed from a position immediately above it, there is no lateral shifting, but the pool still seems to be shallower than it is because some of the rays reaching the eye emerge from the water at a slight angle, and are refracted. Thus, when trying to pick up a stone from the bottom of a stream, we always have to reach down much farther than we think. A stick when placed in water appears bent for the same reason, the eye being deceived by rays which are really bent aside, but appear to be straight, as indicated by dotted lines in the illustration (Fig. 214). Water and air have very different densities, hence the refractive effect is very marked.

If the path of a ray proceeding from water into air is traced, certain important facts concerning refraction will be understood.

A ray, *se*, emerges at the point *e*, and is refracted along the line *er* (Fig. 215). A vertical line *neo* extends through *e*, and is called a *normal* to the refracting surface, just as lines at right angles to reflecting surfaces are normals. In this case of refraction, the air being less dense than water, the refracted ray *er* is bent further away from the normal. This rule is general; when light rays pass from a denser medium into one less dense they are refracted farther from the normal, and *vice versa*. Now, if at equal distances along *er* and *es*, lines *rn* and *so* are drawn perpendicular to the normal, the relative lengths of these lines depend upon the amount of refraction, and if the length of *so* is expressed as a fraction of that of *rn*, a quantity is obtained called the **refractive index** for water and air. For light passing from water into air the refractive index is $\frac{3}{4}$, and one result of this is that a pool appears to be only $\frac{3}{4}$ of its real depth. If light passes from air into water the refractive index is $\frac{4}{3}$.

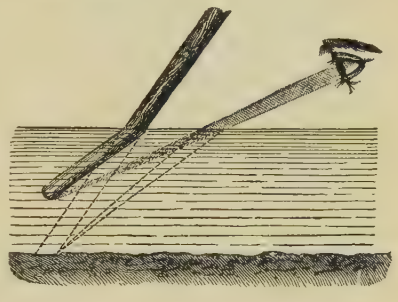


FIG. 214.—REFRACTION CAUSES A STICK IN WATER TO APPEAR BENT.

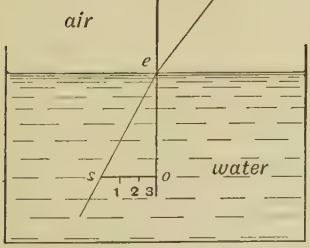


FIG. 215.—A GEOMETRICAL REPRESENTATION OF REFRACTION AND REFRACTIVE INDEX.

A block of ordinary glass acts in much the same way as a pool of water. If a slab of glass about an inch thick is placed on a piece of paper bearing a mark, this mark, which corresponds to the stone at the bottom of a pool, will send light through the glass and into the air. On passing into the air oblique rays are refracted, the eye deceived, and the block of glass appears to be only $\frac{2}{3}$ of its real thickness. The refractive index for light passing from glass to air is $\frac{2}{3}$. These

quantities are constants, the refractive indices always being the same for the same pair of media, and of course the quantities given above are true for light of average wave-length. The refractive index varies slightly with different types of glass.

PRISMS WHICH ACT AS REFLECTORS

In certain circumstances light rays are *reflected* by the surface separating two transparent media, and the effects of refraction can be used to give images similar to those produced by plane mirrors. A few rays proceeding from an object at the bottom of a pool proceed vertically and emerge into the air at right angles to the surface. Such rays pass on without refraction. But most rays pass through the surface obliquely and are bent aside. As shown by Fig. 215, the more oblique a ray is in the water the more oblique is the ray after emergence. Certain rays emerge at such an angle that after refraction they just proceed along the surface of the water. The angle at which such a result is produced is called the **critical angle**, and any rays in the water more oblique than this will not emerge into the air at all; they will be reflected backwards into the water itself, the phenomenon being known as **total internal reflection.** In the case of such reflected rays the surface of the water acts as a plane mirror. A man swimming under water can see only those things out of the water as are situated at a fairly high angle above him. If he glances more obliquely he sees the reflection of objects on the sea floor, provided, of course, the water is not too deep. Similarly, if you visit an aquarium, the surface of the water in the tanks appears as a reflecting surface mostly; only when you are quite close and looking almost vertically can you see through the surface into the air above.

Glass can produce this total reflection, a triangular prism being used for this purpose as a **view finder** in an ordinary hand camera (Fig. 216). Horizontal rays proceeding from the object it is desired to photograph enter an aperture and pass into the glass prism. On reaching the far side of this prism they are totally reflected upwards, and you obtain a view in the top surface of the prism.

Prismatic binoculars or field-glasses make use of the same principle, but since one prism causes lateral inversion as a plane mirror does, the light must pass through another prism which re-inverts the image before it reaches the eye. Thus, in binoculars of this type there are two prisms for each eye, besides lenses which magnify the images. The use of prisms and total reflection enable such field-glasses to give as good a result as would be obtained by a telescope three times their length; there is considerable economy of space. Glass prisms are also employed in the periscope of a submarine. A top prism above the sea reflects light down a telescopic arrangement which magnifies the image of the distant view, and then a second prism reflects the light in a horizontal direction so that the image may be seen by a person in the ordinary upright position.

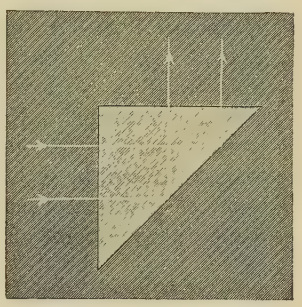


FIG. 216.—TOTAL REFLECTION BY A PRISM USED AS A CAMERA VIEWFINDER.

INSTRUMENTS EMPLOYING A SINGLE CONVEX LENS

If one wishes to see clearly very small writing or marks, a **magnifying glass** is used. This is a **double convex lens,** that is, a thin circular piece of glass having two opposite sides each gently curved and convex or bulging outwards. When such a lens is held in front of, and quite close to, any object, such as printed words on a page of a book, a magnified image of the words is seen, this image appearing at a position behind the lens.

As the lens is moved slowly away from the object, the image becomes larger and larger, but suddenly disappears when the lens is at a certain distance from the object. At a distance greater than this no image is seen.

In order to understand how this image is formed we must trace some of the rays by which it is produced. In the illustration (Fig. 217) the line $eO px$ at right angles to the central

portion of the lens is called the **principal optical axis,** and the point O at the centre of the lens is known as the **optical centre.** If *pq* is an object, say a pin, the rays proceed from this to and through the lens. A ray of light *p* O *e* coincides with the principal axis and proceeds straight on, while another, *qr*, parallel with the first is refracted, so that after refraction it passes through a point F, called the **principal focus** of the lens, and with lenses in general, all rays parallel with the principal axis pass through or appear to pass through the principal focus. The ray *r*F in this case actually does pass through F, but *appears* to come from *y*, a point some distance behind the object. From *q*

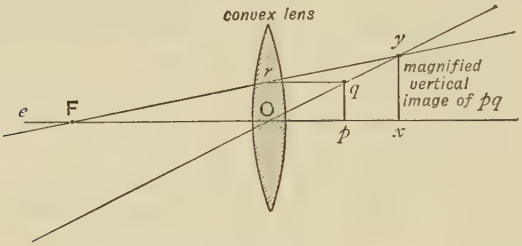


FIG. 217.—A CONVEX LENS FUNCTIONING AS A MAGNIFYING GLASS.

another ray, *q* O, passes through the optical centre and proceeds straight on without deviation, as is the case with all rays which pass through the optical centre. This ray, *q* O, also appears to come from *y*, hence *y* is the position of the upper end of the image *xy*. *This image is magnified, upright, and virtual*—that is, it cannot be caught on a screen—since it appears to be there though the rays themselves do not go there, because they proceed in the other direction.

If the same lens is used as a burning glass, further information concerning images formed by it may be obtained. The sun's rays passing through the lens are focused to one spot on a piece of paper when the latter is at the correct distance. The rays being parallel with the principal axis are all focused to the point called the principal focus, and the distance of this from the lens is called the **focal length** of the lens. Hence to find the focal length, *f*, of a convex lens, focus the sun's rays accurately to a

small spot upon a piece of paper and measure the distance. When you have thus found the focal length of your lens, again use it as a magnifying glass and vary the distance of the object. You will find that in order to obtain an upright virtual image, the object must not be placed at too great a distance, in fact *the lens functions as a magnifying glass only when an object is at a distance less than the focal length.*

But what happens when an object is placed at a distance greater than the focal length? In order to test this it is better to use a lighted candle and do the experiment in a darkened room. Arrange the candle about two inches beyond the focal length and hold a screen of white paper at various distances along

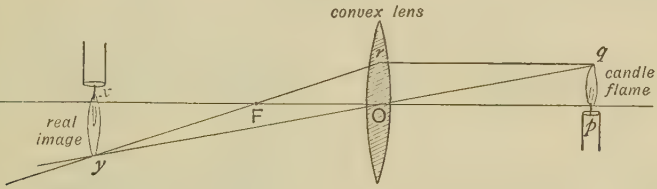


FIG. 218.—THE FORMATION OF A REAL IMAGE BY A CONVEX LENS.

the principal axis, but on the other side of the lens. At one place a clearly defined inverted image is focused on the screen. Since the rays actually converge there, the image is *real*, also it is magnified. The formation of this real image can be explained geometrically by drawing some rays which, being parallel with the principal axis, pass through the principal focus, and others which pass through the optical centre and proceed without deviation (Fig. 218). The lettering on the illustration being similar to that of the previous case a comparison is easy, and it will be noted that the real image is due to the actual convergence of the rays at *y* beyond the lens, instead of an apparent convergence behind it. The **optical projection lantern** and the **cinematograph** operate in this way. An illuminated slide or film is placed at such a distance from a convex lens that a real magnified image is projected upon a screen. As images are inverted, the slide must be placed upside down in order to obtain a picture the right way up.

There is a third case in connection with this sort of lens. Arrange the lens at a distance of several feet from the candle, and you will obtain a real inverted and smaller image on the screen when the latter is fairly near the lens. This third case is of great importance, since it explains the way in which a camera, the eye, and a simple telescope construct images. A **photographic camera** is a light-tight box having a convex lens in front and an arrangement for holding a sensitive plate or film at the back (Fig. 219). Usually there is some arrangement for varying the distance of the lens from the plate, so that a clear or focused image is obtained on the latter. In the camera a convex lens produces a small real and inverted image of an

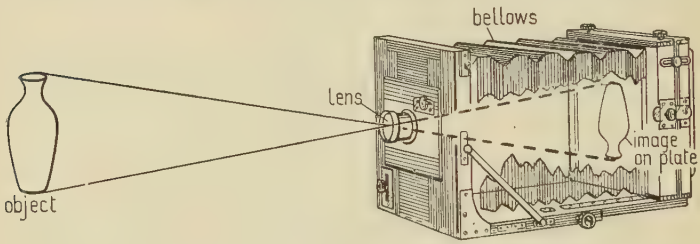


Fig. 219.—The Principle of the Camera.

object situated at a distance much greater than the focal length of the lens.

The correct distance between the lens and the screen at the back is adjusted by expansion or contraction of the bellows or concertina-like part of the apparatus. In order to obtain a clearly defined image only the middle portion of the lens is used, the outer parts, which would produce a certain amount of indistinctness, being covered by an adjustable diaphragm called a ' stop.' By turning a projecting rim the diaphragm is opened or closed as the case may be. This part of the apparatus bears the symbols $f/5{\cdot}6$, $f/8$, $f/11{\cdot}3$, etc., and these refer to fractions of the focal length of the lens. Thus, with the stop at $f/8$ the diameter of the aperture is equal to one eighth of the focal length, and so on, and there is a definite relation between the amount of light passed into the camera and the focal length of the lens. By this

means both the definition and intensity of light are properly adjusted.

The correct focus or position of the lens having been found, a sensitive plate is put in place of the screen, and the photograph obtained by releasing the shutter for an instant. The plate itself is a piece of glass (or gelatine in films) covered with a thin layer of chemicals containing silver compounds, which are affected by the ultra-violet rays accompanying light waves. In general, light coloured and bright objects reflect more of these rays than dark objects, but colours differ considerably in the amount of reflection they give; for example, red reflects very little and comes out dark on the photo. Consequently the ordinary photographic plate does not reproduce accurately degrees of light and shade corresponding to colours occurring in the object itself. **Pan-chromatic plates** specially prepared to respond to various colours give better results, the light and dark portions of the photograph being more in accordance with colours in the original.

Problems on the relative distances of objects and images produced by lenses can be solved algebraically by using the formula $1/v - 1/u = 1/f$ (compare the formula for mirrors). As before, v = the distance of the image, u = distance of the object, and f = the focal length of the lens. The usual convention regarding signs must be observed, and all distances are measured from O, the optical centre. One example will suffice. An object is situated six feet from the lens of a camera, and the focal length is eight inches. How far from the lens must the plate be placed in order to obtain a clear image? As the focal length is given in inches, other quantities must be in the same units.

Now $$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}, \quad \text{hence } \frac{1}{v} - \frac{1}{72} = \frac{1}{-8};$$

$$\therefore \frac{1}{v} - \frac{1}{-8} = \frac{1}{72}; \quad \therefore v = \frac{-8}{72}; \quad \therefore v = -9.$$

The distance of the plate from the lens must be 9 inches.

Many small hand cameras have no means of focal adjustment, the films being placed at a definite distance behind the lens.

In such cases this distance equals the focal length of the lens, and it is assumed that objects photographed will generally be at such distances that their images are formed at the principal focus. Rays from an infinite distance are parallel and are focused at the principal focus, and in photography an object at twenty or thirty feet is far enough from a hand camera for the rays to be regarded as parallel.

THE HUMAN EYE

The **eye** is in structure and mode of working very similar to a camera (Fig. 220). Here again there is a light-tight box, a lens in front and a sensitive screen at the back. The main chamber of the eye is a dark box, which retains its shape because it is filled

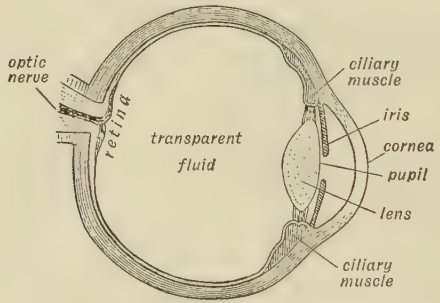


Fig. 220.—Horizontal Section through the Human Eye.

with a transparent fluid. At the front of this chamber is the lens which focuses light rays so that small real images are formed on a sensitive nervous screen called the **retina** at the back of the eye. In front of the lens is an adaptable structure similar to the diaphragm of a camera and performing a similar function, namely, the regulation of light passing through the centre of the lens. This diaphragm or **iris** is the coloured portion of the eye, and the central spot, appearing black because it lets the light through and reflects none, is called the **pupil**. In front of the lens and iris is another smaller chamber filled with a clear transparent fluid covered by the front transparent wall called the **cornea**.

The eye acts in a manner similar to that of a camera supplied with accurate focusing devices. It is not like a small hand camera; if it were we should not see clearly objects placed close to us. But how does the eye adapt itself so that an image is always formed on the retina at the back when the distances of external objects are so varied? The retina remains fixed in position, but the lens itself is composed of soft material, the surfaces of which can be made more convex or less convex as required. These changes in curvature alter the focal length of course, and the shape of the lens is controlled by the **ciliary muscles.** This adaptation of the lens to suit the different distances of external objects is called **accommodation.** The sensations produced on the retina by images are conveyed to the brain by the **optic nerves.** Real images formed by lenses are always inverted, but we do not see objects upside down: *the brain inverts the picture.* This is a case of psychological or mental accommodation.

Now, this mental accommodation remains good throughout life, but that of the eye itself may not do so. Many middle-aged and elderly persons and some children have eyes in which the dark box or posterior large chamber of the eye is either too long or too short. If this is too long (Fig. 221 A), the image formed by the lens falls short of the retina, and the person is said to be **short-sighted.** This defect can be rectified by the use of a concave or diverging lens placed in front of the eye. In **long-sight** the image is formed at too great a distance; it passes beyond the retina (Fig. 221 B), and this can be remedied by placing an additional *convex* lens in front of the eye. Some eyes are irregularly shaped, so that vertical objects are seen clearly though horizontal objects at the same distance are indistinct, or *vice versa.* This defect is known

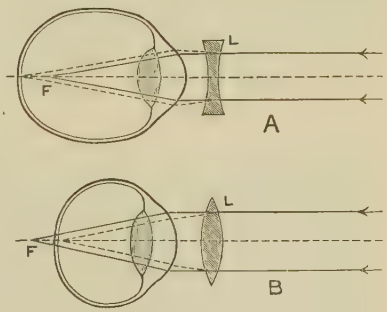


FIG. 221.—EXPLANATION OF SHORT SIGHT (A) AND LONG SIGHT (B).

as **astigmatism** and requires special lenses made according to the prescription of a skilled oculist.

One other point concerning vision must not be overlooked. Objects appear *solid*, that is, having thickness as well as length and breadth, because we have two eyes, and one eye does not see an object from exactly the same view-point as the other. The two pictures are slightly different, but their combined **stereoscopic** effect produces the idea of solidity. A similar effect can be produced in photographs if two photos of the same thing are taken from slightly different positions as if seen separately by the two eyes. These photographs are then mounted side by side and viewed together by the observer looking through two separate magnifying eye-pieces, one for each eye. Provided the photo which should be on the left side is on the left, and the other on the right, the objects seen in the photograph appear solid and the arrangement is called a stereoscope. The application of this principle to the cinematograph would give very realistic pictures but would be difficult and very expensive.

TELESCOPES AND MICROSCOPES

A simple **refracting astronomical telescope** is an arrangement for obtaining a view of distant objects. Two convex lenses are mounted in tubes, so that by sliding one tube within the other

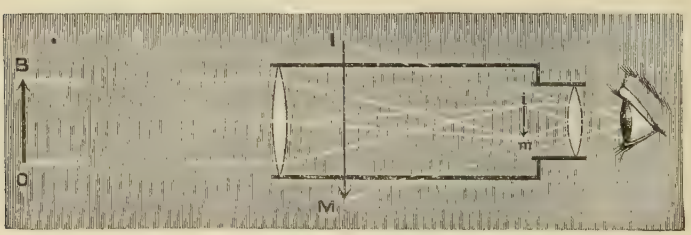


FIG. 222.—THE PRINCIPLE OF AN ASTRONOMICAL TELESCOPE.

the distance between the lenses can be adjusted and the images thereby focused correctly (Fig. 222). The lens at the larger end of the telescope is called the **object glass**, and since rays proceeding from an object at a great distance are parallel, a real

image of this object is formed at the principal focus. The other lens or **eye-piece** is then brought near this real image, so that a magnified virtual image (IM) of it is seen. Since the real image is inverted, this virtual image is also upside down, a fact of little consequence in astronomical work, but one that does matter when terrestrial objects are viewed by such persons as surveyors and sailors. In a **terrestrial telescope** the real image formed by the object glass is re-inverted by another convex lens before it is magnified by the eye-piece.

Opera glasses (Fig. 223), for use at theatres, and ordinary field-glasses which do not make use of total reflection by prisms, are rather different from the ordinary telescope. They are binocular,

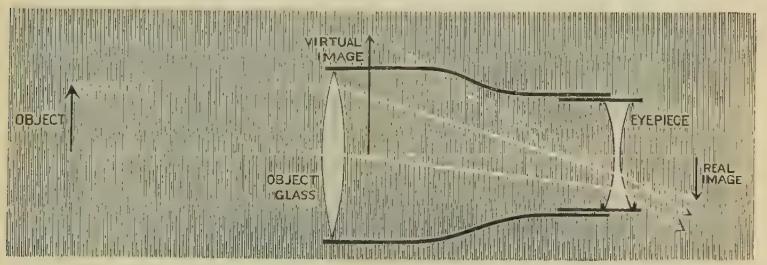


FIG. 223.—THE PRINCIPLE OF THE OPERA GLASS.

so that both eyes can be used, but apart from this the formation of images is not quite the same. As in a telescope, a convex lens produces a real image, but the rays which produce this image are intercepted and caused to diverge by a double concave lens forming the eye-piece. The image actually seen is virtual, magnified, and re-inverted, this last feature constituting the chief advantage of this class of instrument. The magnification is not so good as that obtained with an ordinary telescope, but is sufficient for viewing a stage or a horse race. This is the class of telescope invented by **Galileo** and used by him in his observations on the moons of Jupiter.

A **microscope** is an arrangement of lenses used for viewing extremely small objects, and resembles a telescope in having the lenses mounted in metal tubes (Fig. 224).

In a microscope an **objective** or convex lens of very short focal length is used to produce a magnified real image of the minute object. This case is similar to the production of an enlarged real image by an optical projection lantern, and with either instrument the object must be placed at a distance from the lens slightly longer than the focal length. The real inverted image formed within the barrel of the microscope is again magnified by another convex lens, the **eye-piece,** which produces a virtual image which remains upside down.

Greater magnification can be obtained by using another objective having a shorter focal length, but of course, this objec-

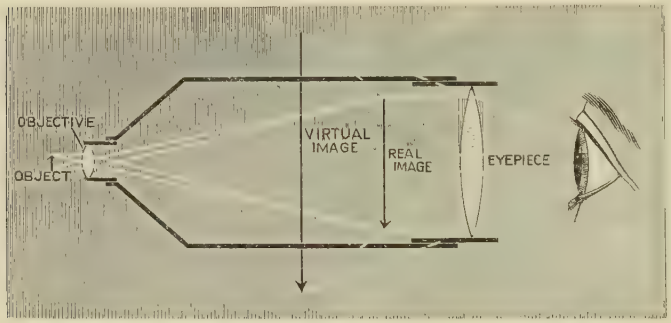


Fig. 224.—A Compound Microscope.

tive must then be brought nearer to the object. An ordinary low-power objective commonly used in biological or other work has a focal length of about one inch, and magnifies an object so that its *length* appears about twenty-five times as long as it really is. A high-power objective gives a linear magnification about 100 times the original size.

If either the eye-piece or objective of a microscope is examined, it is found that it consists of not merely one lens, but a combination of lenses. The image obtained by a single lens is not so accurate as it should be, because the light is dispersed into the colours of the spectrum.

Produce on a piece of white paper a real image of a candle flame formed by an ordinary convex lens. If the paper is

moved slightly backwards and forwards it is seen that the edge or boundary of the image is coloured, violet when it is nearer the lens, and red when it is a little farther from the lens. This is what one should expect, since violet rays are refracted more than red rays. The formation of these coloured images by single lenses is called **chromatic aberration** (Fig. 225 (i)), and the combination of lenses in an eye-piece or objective is a device for the prevention of such aberration. An **achromatic lens,** as used in good microscopes and telescopes, consists of a convex lens composed of crown glass placed against a concave lens

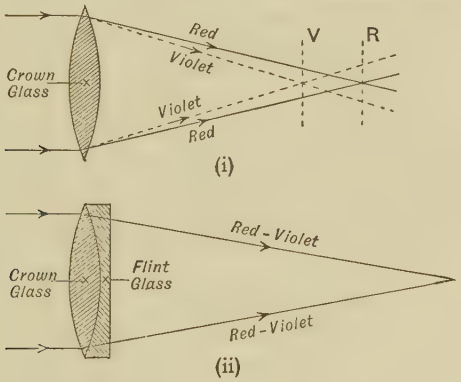


FIG. 225.—A SIMPLE LENS AND AN ACHROMATIC LENS.
IN AN ACHROMATIC LENS ALL COLOURS ARE FOCUSED AT THE SAME PLACE.

composed of denser flint glass (Fig. 225 (ii)). In such a combination the dispersion by one lens neutralises that of the other, though the arrangement *as a whole* still functions as a converging or convex lens, the focal length of the convex portion being shorter than that of the concave part.

Lenses are useful in other ways besides the formation of images. As in the case of a parabolic mirror, if a source of light is placed at the focal point a beam of parallel light can be obtained, but of course the light passes through the lens and is not reflected by it. The practical application of this is of great importance in cases where it is desired to project a beam of light in any direction and not merely in one direction. The

best known example is a lighthouse, where a beam of gently diverging light is first flashed one way then in another direction. As very large lenses are extremely difficult to make, heavy, and very costly, the light is passed through an arrangement composed of many glass prisms or dioptric lenses which give the desired result (Fig. 201). The apparatus is rotated so that the beams sweep round the horizon and appear in any given direction at regularly timed intervals.

Mast-head lamps and others on ships are similarly fitted with dioptric lenses so that the beams diverge slowly and are seen in many directions.

CHAPTER XXVI

SOUND AND MUSIC

The sense of hearing is a psychological or mental effect resulting from a physical cause. We perceive a sound, whether it is harsh and noisy or pleasant and musical, because some external cause makes impressions upon the nerves of our ears. The external causes which produce in our brains the sensations we call sounds are varieties of wave motion occurring in matter—air, water, metals or other substances as the case may be. We have seen that light which may produce the sensation called sight consists of wave motions in ether, not in ordinary matter, thus differing greatly from sound. If an alarum clock is placed under a glass bell jar over an air pump, and the air removed, the vibrating alarum makes no noise though the hammer is seen in motion. Ether occupying the vacuum transmits light, but there is no air or other material substance to transmit sound waves.

The transmitting media being so very different in the two cases, it is not surprising that resulting features such as wave-length and velocity are also very dissimilar. Light waves are only millionths of an inch in length, but travel at the enormous speed of 186,326 miles per second, whereas sound waves traversing air may be measured in feet though they only proceed at a velocity of some 1100 feet in one second. The velocity of light has been accurately determined by several independent methods, one of the most recent being that of Professor Michelson of Chicago, who caused light to be sent from one mountain to another at a distance of 22 miles away. A fixed mirror on the second mountain reflected the light back to the first, and the interval of time taken by the light to perform the double journey of 44 miles was carefully measured by means of suitable apparatus.

The velocity of sound has been determined in a very similar way by noting the interval of time taken by a sound wave in traversing a definite number of miles. When a gun at a certain locality is fired, observers at a distant place see the flash and commence to count the interval of time which elapses before the sound is heard. The velocity of light by which the flash is seen is so great that the time taken by it, a very minute fraction of a second, can be ignored when the speed of the incomparably slower sound is to be determined.

Sound waves travel through various material substances or media at different velocities, but we must first consider the nature of the waves which constitute sound itself. In most cases the transmitting medium surrounding the ear is air, and practically all sounds, pleasant and otherwise, are transmitted by this medium, hence the nature of sound waves in air are of particular interest. Waves of the sea and light waves in ether are transverse, that is, the oscillations take place in a direction at right angles to that in which the wave motion itself travels. But sound waves in air are *longitudinal*, the particles move backwards and forwards in the *same* direction as that along which the wave motion proceeds. When air particles are pushed forwards or compressed a condensation occurs at one place and a rarefaction at another place (Fig. 226). Then because the air is elastic the particles return, but overshoot the mark, producing a rarefaction where before there was a condensation. These forward and backward oscillations are communicated from one set of air particles to the next set, and so on, the alternating compression and rarefaction thus constituting a type of wave motion which proceeds outwards in all directions from the disturbance that produces it.

The rapid to and fro motions of a tuning fork impart wave motion to the air and are an example of a *regular* disturbance producing a musical note, while the blows of a sledge hammer may serve to illustrate the kind of cause which produces an *irregular* disturbance resulting in the sensation called a noise. In either case longitudinal waves consisting of alternating compressions and rarefactions pass through the air and reach the ear, but those due to the tuning-fork are properly timed and regular in form, whereas those produced by the sledge hammer are badly

timed and irregular. But whether they produce musical notes or irregular noises the wave motions travel through the air with the same speed, the actual value of which depends upon the temperature and density of the air at the time. *When the air is of average density and its temperature is* 0° *C. the velocity of sound waves through it is* 1088 *feet per second*, and this rate increases by about 2 feet for every additional degree Centigrade, since warm air is less dense than cold air, and the speed of sound in gas is increased by a decrease of density.

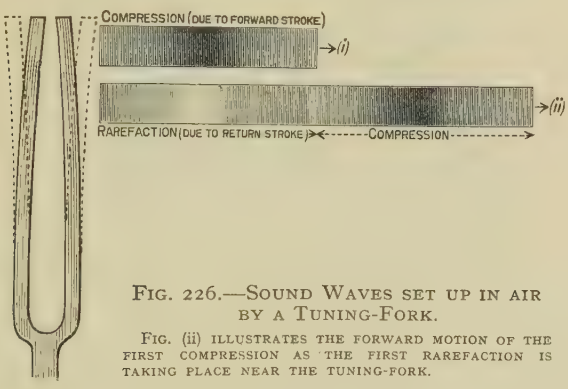


FIG. 226.—SOUND WAVES SET UP IN AIR BY A TUNING-FORK.

FIG. (ii) ILLUSTRATES THE FORWARD MOTION OF THE FIRST COMPRESSION AS THE FIRST RAREFACTION IS TAKING PLACE NEAR THE TUNING-FORK.

During a thunderstorm on a warm summer day the air temperature is such that the noise of thunder travels about 1120 feet per second, hence the actual distance of the lightning from an observer can be found by a simple calculation. When the lightning is seen at the same moment as the thunder is heard, the electric discharge is dangerously near, only a few hundred yards overhead. In a denser gas, such as carbon dioxide, the velocity of sound is less than it is in air, but in hydrogen or other light gases and in air rendered less dense by the presence of much water vapour the velocity is greater.

Sound waves in liquids and solids are also longitudinal in nature, but they proceed at very much greater speed than in a gas. In water the velocity is more than four times as great as it is in air, and the loss of energy is less, facts which explain why the sound of the paddles of a steam-boat are

heard even when the ship is at a great distance from land. In rigid solids, particularly in metallic rods and wires, sound waves travel at a greater speed still; for example, in steel its velocity is more than 16,000 feet per second. The approach of a distant tramcar can be perceived long before it comes in sight if an ear is placed against one of the posts supporting the overhead wires conveying the electric current. These wires and posts conduct the sound much more quickly and with less loss of energy than the surrounding air does.

ECHOES AND THE HYDROPHONE

Mirrors reflect light, a breakwater reflects sea waves, and many objects, such as walls, high buildings, and hills, send back sound waves which strike them. The reverberating nature of thunder is due to repeated reflections of sound by clouds. Actually, one flash of lightning is accompanied by one original sound. When a person situated at a sufficient distance from a cliff shouts, the noise is heard again after a slight interval of time, the **echo** or second noise being due to the reflected sound wave reaching the ear. If the cliff is too close, the ear is unable to separate the original sound from the echo, their perception is simultaneous. *In air this necessary minimum distance is about* 110 *feet.* When a cliff or hill is at too great a distance the returning sound waves are so weakened that they do not produce any audible effect. If rays of light or waves of sound are to remain strong over considerable distances they must be projected as parallel beams, and not be permitted to spread outwards in all directions. A parallel beam of light is projected by a searchlight, and with suitable apparatus a parallel beam of sound can also be projected. The reflection of such a sound beam by an iceberg or hidden rocks can be utilised to determine the direction and distance of such submerged objects, provided a sensitive apparatus is used to detect the return of the sound waves.

An apparatus for the detection of the sound waves traversing water is called a **hydrophone** (Fig. 227), and consists of a disc which, vibrating under the influence of sound waves, operates a microphone and thus produces audible effects in attached

telephones (Microphone, Chapter XXVII). Only one side of the hydrophone is exposed to the action of sound waves, hence the direction of sounds received is clearly indicated. During the Great War this instrument was much used for the detection of enemy submarines, which of course created their own sounds.

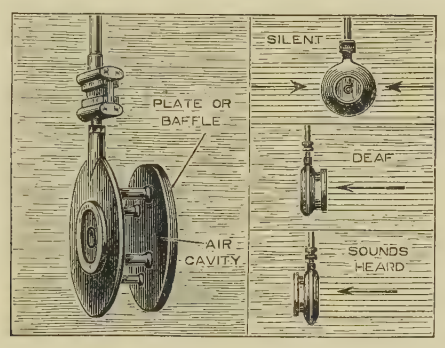


FIG. 227.—THE HYDROPHONE

FOR DETECTING SOUND WAVES BENEATH THE SURFACE OF THE SEA. THE USE OF A BAFFLE PLATE ENSURES THAT SOUNDS ARE HEARD ONLY IN ONE DIRECTION.

If sound waves are permitted to spread they become weakened, and the converse is true; sound over a larger area can be concentrated to a smaller area, thus producing a magnified effect at the point of concentration. This is the principle of the **ear trumpet** used by deaf persons. In speaking tubes and in a physician's **stethoscope** sounds are conserved within the tube, while in a **megaphone** sound waves are projected in such a way that they spread slowly, hence they can be heard at some distance.

PITCH AND FREQUENCY

Though sound waves are longitudinal they have definite wave-lengths and frequencies. *The wave-length is the distance between two consecutive positions of maximum compression, or, of course, that between two consecutive positions of maximum rarefactions.* The frequency is the number of waves or oscillations per second, and, as in the case of light, the wave-length multiplied by the frequency is equal to the velocity or distance

per second that the sound travels. For example, if the velocity is 1125 feet per second and the wave-length is $4\frac{1}{2}$ feet, then the frequency is 250.

When the wave-lengths are relatively large and the frequency correspondingly small, low musical notes or noises are heard. The lowest notes produced by an average piano have a frequency of about 30, and waves of considerably lower frequency exist but are not all heard as sound. Similarly, frequencies which are too great are not audible, since the ear can perceive only frequencies within certain limits, roughly from 16 to 16,000 per second. A low bass note is said to have a low **pitch,** a high treble note a high pitch, and so on; hence *the pitch of any note is determined by the frequency.* The loudness or intensity of any note or noise is not the same thing as pitch, and is not the result of frequency, but is determined by **amplitude,** or the degree of compression and rarefaction irrespective of wave-length.

There are many everyday examples of the influence of frequency upon the pitch of a note. A circular saw gives a higher note if its speed of rotation is increased, similarly with the toothed wheels in the gear box of a motor car, the rotating parts of machinery, the wheels of a railway carriage, and so on. The high pitched piping note accompanying the flight of a mosquito is caused by the extremely rapid beats of the wings, some hundreds per second; in fact the note emitted by an insect in flight is a fairly good indication of the rapidity with which the wings vibrate.

When any arrangement producing a note of definite pitch is quickly rushed towards or away from a hearer, the pitch appears to rise or fall because the wave-length shortens slightly as the object approaches and lengthens as it recedes. This means that an increase of frequency with higher apparent pitch occurs on approach, and a decrease in frequency with an apparent lower pitch on receding. The whistle of an express locomotive illustrates this principle. It should be realised that in reality the pitch of the whistle itself remains constant; it is the *frequency of the waves reaching the ear* that is increased or diminished.

That it is the frequency which determines the pitch of a note can be shown by means of an apparatus called a **siren.** There

are various forms of such apparatus, a simple kind consisting of a disc pierced by a number of holes (Fig. 228). If a stream of air is directed against these holes as the disc is rotated, a note is obtained and the pitch depends upon the number of holes the air encounters in a second. By causing the disc to rotate at a greater speed, a higher note is produced. Some sirens used on ships are based upon this principle, though many are merely enlarged tin whistles operated by blasts of steam. The note obtained from a disc siren is due to regularly timed puffs of air passing through the holes and causing compressions in the external air. In such an apparatus used for actual measurement of frequency there are dials which register the number of revolutions of the disc. This number multiplied by the number of holes gives the frequency, and it is obvious that the frequency of another instrument, say a tuning-fork, can be determined by the adjustment of the siren to give the same note as the tuning-fork.

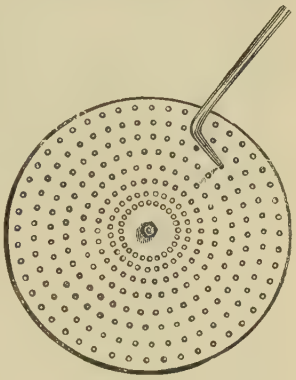


FIG. 228.—A DISC SIREN.

THE MUSICAL SCALE AND THE PIANO

Physically, music is concerned with the production of notes and of simultaneous groups of notes, the combined frequencies of which produce pleasant or harmonious sounds. Psychologically, music is much more than this since it is the expression of emotion or 'feeling' in addition to the production of sounds which are merely harmonious. Technique alone does not produce a Kreissler or a Mendelssohn.

The origin of music must be traced to the attempts of primitive man to express his feelings by means of sounds. The most ancient of all musical instruments is undoubtedly the human voice, and the earliest types of concerted music were probably in the nature of war cries and folk songs. Later, it was dis-

covered that notes could be produced by beating objects and by blowing air through pipes. The evolution of the earlier types of musical instruments is a matter largely wrapped in obscurity, such knowledge as we possess being obtained from old mural decorations and the discovery of actual instruments and models. Wind instruments similar to the flute and primitive reeds of the shepherd's pipe type were used in Egypt thousands of years ago. Ancient models of the *Hydraulus*, or water organ, show that the Romans possessed organs in which the air necessary to operate the pipes was maintained under pressure by means of water, and admitted to the pipes by means of keys on a keyboard. Pictures on stone slabs obtained at Nineveh prove that the dulcimer, the remote ancestor of the piano, was used by the Assyrians more than a thousand years before the time of Christ. Hand hammers were employed with the dulcimer, keys being introduced during the middle ages in the clavichord, improved in the harpsichord, and more or less perfected in the piano, the earliest types of which appear to have been introduced about the year 1700 A.D. Violins, which developed from viols, attained the greatest degree of perfection at that time when **Stradivari**, then in his prime, and **Guarneri of Cremona**, described as the 'Michael Angelo of fiddle makers,' produced instruments that are rarely equalled at the present time.

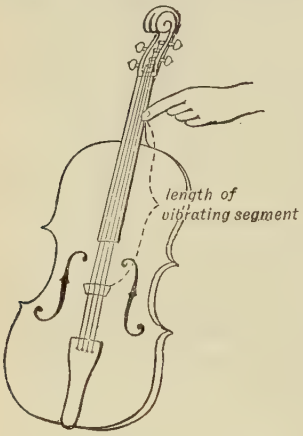


FIG. 229.

IN INSTRUMENTS OF THE VIOLIN CLASS THE LENGTH OF VIBRATING SEGMENTS CAN BE ADJUSTED BY MEANS OF THE FINGERS, HENCE FEW STRINGS GIVE MANY NOTES. IN A PIANO EACH STRING IS OF FIXED LENGTH AND GIVES ONLY ONE NOTE.

The relations of various musical notes to one another can be understood by reference to a piano, an instrument consisting of many stretched steel wires, each wire being struck by a hammer so that it vibrates and gives out a note when required.

In the musical scale there are seven notes, and these in their usual order are named respectively *C*, *D*, *E*, *F*, *G*, *A* and *B*. Each

note has a definite frequency in any given system of pitch. When a piano or other instrument is tuned to the **French normal diapason pitch,** the system in common use, the frequencies of the middle white notes from *C* to *B* respectively are 256, 288, 320, 341·3, 384, 426·6, and 480. In the so-called **concert pitch of the Philharmonic Society** the frequencies are a little higher than these; for example, that of middle *A* is 439. Many large organs have pipes of such lengths that the notes produced are of this concert pitch, hence other instruments must be tuned in agreement. At considerable expense certain organs, for example that in the Albert Hall, London, are being altered to give notes of the normal diapason pitch, which is considered better by the majority of musicians. Military bands observe a pitch still higher than that of the Philharmonic Society, the middle *A* having a frequency of 452. Bands playing in the open find that a higher pitch is better, since changes in temperature of the air modify the pitch considerably; this is particularly the case in hot climates, such as that of India.

Though there are these different schemes of pitch, instruments remain in tune *provided the relative frequency of each note is correct with regard to the others.* It is a matter of *ratio*, and the ratios of the frequencies of notes from *C* to *B* inclusive are represented by the numbers 24, 27, 30, 32, 36, 40 and 45.

A 'black' note on a piano has a frequency intermediate between those of the two white notes adjacent to it. Thus a certain black key between *A* and *B* gives a note called either *A* sharp or *B* flat in practice, though theoretically there is a difference between them.

There is quite a large number of white keys on a piano, and any eight notes, say from middle *C* to the next *C* inclusive, constitutes an **octave.** The higher *C* has a frequency just double that of middle *C* at the lower end of the octave. Any one of the seven notes from *C* to *B* has corresponding notes in higher octaves, and the frequencies of these higher notes are multiples of that of the original or **fundamental** note. Similarly the notes in lower octaves have frequencies which are sub-multiples of that of the fundamental. These notes which are either multiples or sub-multiples of the corresponding middle notes are called **harmonics,**

and, of course, there are many harmonics of one note. Thus middle *C* at a frequency of 256 has, as harmonics, notes of frequencies 512, 1024, and so on up the piano keyboard, and sub-multiples such as 128, 64, and 32 going down the keyboard. It will be observed that these particular frequencies give harmonics *and* octaves of middle *C*, but there are other harmonics, such as the note of frequency 768, which are not octaves. All octaves are harmonics, but all harmonics are not octaves.

Harmonics occur in other forms of wave motion besides sound. In wireless reception a broadcasting station can be received on a wave-length double (frequency half) or half (frequency double) that of its proper wave-length, but reception of these harmonics gives much weaker volume than that obtained when a station is tuned in to its correct fundamental wave-length.

In music, it usually happens that a fundamental note and its harmonics are heard together, the combined result generally producing a very pleasing effect. The *quality* of a note largely depends upon the combination of harmonics and this partly explains the differences of the same notes played upon different instruments, the piano and violin, for example. The sixth harmonic produces a harsh effect, and to prevent the presence of this the hammers of a piano strike the wires at a spot $\frac{1}{7}$th of their length from one end.

Now let us consider the actual mode of sound production by a piano or by any of the so-called stringed instruments. In a piano steel wires struck by hammers produce the sounds, in a violin the strings composed of catgut are caused to vibrate by the friction of a bow, but in either case the underlying principles of note production are the same. In a laboratory the study of sounds produced by stretched wires is made by means of an instrument called a **sonometer** (Fig. 230). This consists of two thin steel wires, stretched above a long hollow wooden sound-board. Two wires are used so that when desired one can be kept constant, the other varied. Both wires are firmly fixed at one end, and the other ends can be tightened either by pegs similar to those of a violin, or by passing the wire over a small wheel and attaching heavy weights. This latter mode is employed when it

is desired to investigate the effects of tension on the vibrating wire. Two fixed 'bridges,' one at either end, fix exactly the maximum length of wire capable of vibration. Movable bridges can be placed at suitable places so that a wire can be divided into two or more vibrating segments.

When one of the wires of a sonometer is tightened and plucked it gives out a certain note called the fundamental. The wire itself vibrates transversely though it originates longitudinal sound waves in air, and it is this resulting wave motion in the air that affects our ears. This fact must not be overlooked, as it explains the action of all stringed instruments; the strings themselves vibrate in a direction at right angles to their length, but the

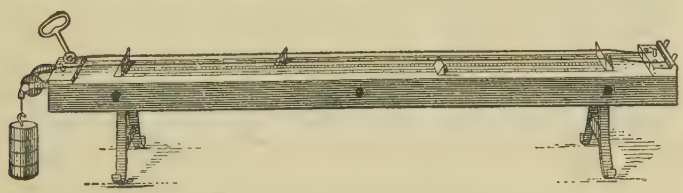


FIG. 230.—A SONOMETER.

air between our ears and the instruments vibrates in the usual longitudinal manner characteristic of sound waves in a gas. By adjusting the tension by weights the wire can be made to give any well-known note, such as middle *C* of the piano.

Now, if a movable bridge is placed exactly at the middle point of the stretched wire, there will be no transverse vibration at this middle point; the wire as a whole is divided into two equal vibrating segments, and the note produced is the **first harmonic** one octave higher than the fundamental. If the bridge is placed at a point $\frac{1}{4}$ of the length of the wire, four vibrating segments are produced and the resulting note is the **second higher octave** of the fundamental note. The points at which there is no transverse motion are called **nodes,** the vibrating parts are **internodes,** and strips of paper will remain at the nodes but are thrown off if placed at positions on the internodes.

Careful experiments with the sonometer show that (1) *the frequency of vibration and consequently the note produced is inversely proportional to the length of wire.* This explains the

use of shorter wires for the higher notes of the piano, and the shortening of a violin string by the finger when a higher note is to be played. (2) *The frequency is proportional to the square root of the tension.* A certain piano note is produced by a wire of given length, and if this note is flat it can be put in tune by increasing the tension. Other stringed instruments are tuned up in the same way. (3) *With wires of given length and tension the frequency is inversely proportional to the weight of the wire.*

It is more convenient to use heavy wires for base notes on a piano than to have them very long or to have a tension very different from that on the other wires. For the same reason the fourth or G string of a violin is loaded with wire.

THE ORGAN AND WIND INSTRUMENTS

A stretched wire fixed at each end exhibits a wave motion that cannot proceed beyond the fixed ends, hence this sort of motion is frequently called **transverse stationary undulation.** A column of air in an organ pipe affords an example of stationary *longitudinal* vibration. The effect of such a vibrating air column can be observed if a tuning-fork is held over the mouth of a tall glass cylinder containing air (Fig. 231). When a certain quantity of water is poured into the jar the length of the air column is so adjusted that it vibrates in time with the tuning-fork and the note is considerably reinforced. The air vibrating in sympathy with the tuning-fork is said to **resound,** and the note produced is an example of **resonance.** This resonant effect will be produced only when the air column is of the correct length for the note given by the fork.

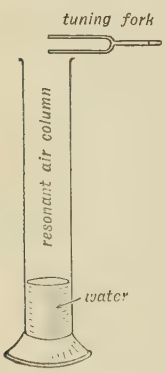


FIG. 231.—REINFORCEMENT OF A NOTE BY AN AIR COLUMN.

In an organ pipe the air is caused to vibrate by a different means. An organ consists of a collection of wooden and metal pipes, of various sizes, the whole instrument resembling, in many ways, a set of tin whistles. Air is forced through an opening

at the end of each pipe and directed against the edge of an aperture at the side (Fig. 232). This throws the whole air column into stationary undulation and the length of the pipe determines the frequency of the reinforced note. If the pipe is closed at the further end, the wave-length is *four* times that of the pipe, but if it is open, the wave-length is *twice* that of the pipe. It is evident that an open pipe has a frequency twice as great as that of a closed pipe, and gives a higher note, and of course shorter pipes give higher notes than longer pipes of the same type. The keys on the manual of an organ simply release the air so that it enters the corresponding pipes.

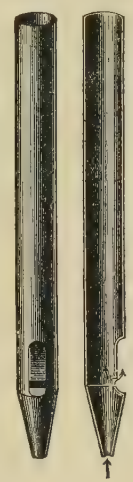


FIG. 232.—ORGAN PIPES.
FRONT VIEW AND SIDE VIEW OF VERTICAL SECTION.

A tin whistle resembles an organ pipe in its mode of sound production, a blast of air being directed against a thin edge at an aperture in the side of the tube. But it differs from an organ pipe in having six holes in the side. The wave-lengths, hence the frequencies and notes, are produced by removing the fingers from the holes, since *an open hole determines the end of the resonant column of air.* The vibrating air column extends from the aperture near the mouth down as far as the first uncovered hole. Wave-lengths and frequencies are similarly adjusted for various notes in some other wind instruments.

In cases like the **clarinet, oboe,** and **bassoon** a vibrating tongue-like structure called a **reed** is employed to throw the air column into resonant vibration, hence these are known as reed instruments (Fig. 233). The human voice is the result of vibration of two membranes or **vocal chords** stretched across the part of the throat called the **larynx.** A narrow gap between the chords permits air to pass, and the note obtained depends partly upon the force of the air and partly upon the tension on the chords. In childhood these chords are relatively short so that the voice is of higher pitch than that of an adult.

Certain modern appliances provide us with second-hand speech and music, the most popular of these forms of apparatus being the **gramophone**. In this, a steel needle moves under the influence of irregularities in the surface of a circular black disc commonly known as a ' record.' The irregularities correspond to the original sound vibrations that impressed their wave forms upon a soft wax disc at the time the actual performance of speech or music was taking place. The wax is covered with metal by an electrolytic process (see Chapter XXVIII), and a die is thus obtained by means of which accurate copies can be stamped upon

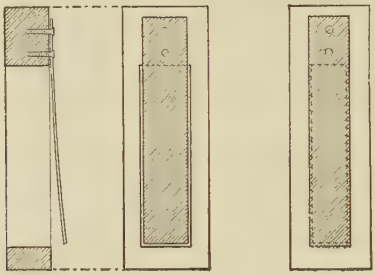


FIG. 233.—VIBRATING REEDS.

(i) SIDE AND FRONT VIEW OF A ' FREE ' REED AS USED IN A CONCERTINA AND ' MOUTH ' ORGAN. (ii) A ' BEATING ' REED IN WHICH THE REED IS LARGER THAN THE OPENING BEHIND IT. SOME ORGAN PIPES HAVE REEDS OF THIS TYPE.

the black records sold to the public. The movements of the steel needle are communicated to a mica disc within the sound box of the gramophone and the motions of this disc faithfully reproduce the original sounds. In many modern hornless types of instrument the sounds are reinforced by the resonance of air in a cabinet.

In a telephone, sounds are reproduced by electro-magnetic means, as described in the next chapter.

THE EAR

The organ by means of which we perceive sounds occurring in the external world is both delicate and complex. The human ear consists of three main parts. The **outer ear** consists of a flap

communicating with a relatively wide passage or tube, the arrangement functioning as a collector of sounds. The middle ear or **tympanum**, commonly called the **drum**, is a body containing three little bones capable of being thrown into vibration

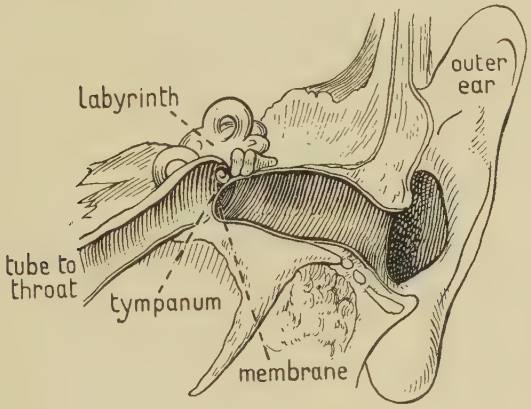


FIG. 234.—SECTION THROUGH THE HUMAN EAR.

by sound waves entering the outer ear. In order that conscious sensations corresponding to these vibrations may be perceived by the brain a system of nerves is necessary, and these are situated in the inner ear or **labyrinth**, so called on account of its complex structure.

CHAPTER XXVII

MAGNETISM AND ITS RELATION TO ELECTRICITY

NATURAL AND ARTIFICIAL MAGNETS

The name magnet is derived from Magnesia in Asia Minor, where, at a very early date, it was observed that certain specimens of a mineral oxide of iron, now known as **magnetite**, possessed the power of attracting pieces of iron. Magnetite is a black mineral occurring extensively in Sweden, Spain, and North America, but it is not always magnetic. Specimens possessing

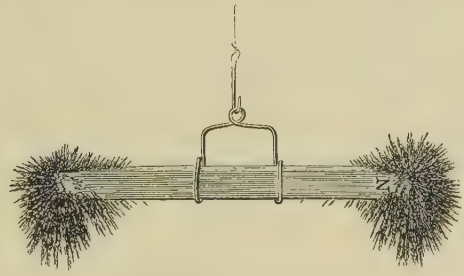


Fig. 235. Iron Filings adhering to the Poles of a Bar Magnet.

magnetic properties are known as **lodestone** (*i.e.* leading stone), and if one of these is placed in a heap of iron filings and then withdrawn, clusters of filings adhere to the lodestone, particularly at two opposite parts commonly called **poles.** A small bar magnet behaves in a similar way when placed in iron filings (Fig. 235). Hardly any filings adhere to the middle part of the bar, though large numbers are clustered around the two ends near which the poles are situated.

The magnetic force of attraction appears to be more concentrated at these poles or positions near the ends, but it is more correct to say that the magnetism near the centre of the bar is not *free* to exert an influence on outside objects as it is in the region of the poles. By comparison of the number of small nails or tacks which can be supported by the middle of a bar magnet with the number supported at other parts of the magnet, it is possible to form some idea of the distribution of free magnetism in the magnet as a whole.

If a magnet is fairly large and in good condition the filings or tacks may jump to the magnet, thus illustrating the fact that magnetism is a force which acts across apparently empty spaces, and in this it resembles gravitation. But magnetism differs from gravitation in exerting an appreciable force only upon certain substances, chiefly iron and steel ; moreover, in certain cases the force is one of repulsion, endeavouring to push or repel steel objects away from the magnet instead of attracting it. Gravitation is always a force of attraction, and all objects are influenced by it, though in different degrees of intensity according to their joint masses and distances apart.

The forces exerted by a magnet are connected with the way in which the molecules or minute particles of the substance are arranged within the bar, and this can be shown by placing some steel filings inside a glass tube and by magnetising the filings by a simple stroking process (Fig. 236). The experiment also shows that magnetic influence passes through glass. Bring down one end or pole of a bar magnet upon one end of the tube, then slide the magnetic pole along the tube as indicated by the arrow in the figure. Next raise the magnet away from the tube, bring the same pole down again on the glass tube at the end where you began the first stroke and repeat. When this is done several times the influence of the magnetic pole causes the filings in the tube to arrange themselves in an

FIG. 236.

AN EXPERIMENT TO MAGNETISE STEEL FILINGS IN A GLASS TUBE.

orderly and linear arrangement. Each filing becomes a little magnet, and arranges itself in proper linear position relative to the other filings. So long as this linear arrangement of the filings is retained the contents of the tube behave as a bar magnet, capable of attracting iron filings, tacks, etc., but if the arrangement is shaken and the filings thrown into a disorderly mass, the magnetism ceases to exist as a force capable of influencing external objects.

This is true of magnets in general. The stroking process arranges the molecules or tiny particles of a steel bar so that they arrange themselves in a manner similar to that of the filings in a glass tube. Any process which disturbs the orderly arrangement of particles, such as banging the magnet on the floor, or heating it strongly, destroys the magnetism. This explains why magnets lose their magnetism if they are not handled carefully.

What happens if iron filings are placed in the tube instead of steel? It will be found that the *iron is magnetic only so long as it is under the influence of a magnet*, whereas steel once magnetised retains its magnetism, whether another magnet be present or not, provided that it is treated properly. This difference in the magnetic behaviour of iron and steel has proved extremely valuable, since the working of many electrical machines depends upon this property. If iron, once magnetised, retained its magnetism, electric appliances, such as bells, motors, and dynamos, would not work properly. On the other hand, magnetos employed on motor cars, and the indispensable mariner's compass used for steering ships, are examples of appliances which depend upon the fact that steel retains its magnetism.

Another difference must be noted. Iron, provided it is adequately excited by suitable magnetic means, is capable of exerting a much greater magnetic force than steel can in similar circumstances, and this is again fortunate since iron *must* be used in electric motors, dynamos, and many other machines.

Since steel retains its magnetism, a single bar magnet can be used to magnetise any number of steel objects, but it must not be concluded from this that we obtain something for nothing. Several magnets may be made, each capable of lifting nails or doing

other work, because of the mechanical work done in stroking the various pieces of steel. Energy has been expended in the process of magnetisation and in virtue of that energy we may obtain magnetism capable of doing work.

We have seen that magnetism is in some way connected with an orderly arrangement of the ultimate particles composing a substance, and a particularly important result of such linear arrangement is the property known as **polarity.** Any properly magnetised bar has two poles of equal magnetic strength, but these poles differ in their behaviour towards other magnetic bodies, because the inherent magnetic properties of one pole are not the same as those of the other. When a bar magnet is either suspended by a fine thread or floated upon a piece of wood in water, it swings round until it comes to rest with one end pointing to a position near the geographical north, the other end pointing roughly towards the geographical south. The end which points northwards will continue to point northwards every time the experiment is tried, unless the magnetism is destroyed or reversed. For this reason the pole near that end is popularly called a north pole, though the term *north-seeking* pole is more accurate. Similarly, the pole near the other end is called a south or *south-seeking* pole.

A bar magnet properly mounted so that it is quite free to move in a horizontal plane is called a **compass needle,** since the magnet is very much longer than it is wide. One clearly marked end or north pole of such a compass always points towards the north, hence the great value of such an instrument in navigation, exploration, and surveying. Of course, any compass indicates direction correctly only provided that it is not improperly influenced by any lumps of steel or iron placed near it, hence a ship's compass must be suitably screened from iron and steel parts of the ship. The binnacle which contains a ship's compass also contains *corrector* magnets to counterbalance undesirable magnetic influences.

The **mariner's compass** consists of a magnetised bar with a card bearing the various directions—north, south, etc.—correctly mounted above and firmly attached to it, so that as the magnet moves in relation to the ship's course, the card moves with it.

The box containing the compass is mounted by means of gymbals, so that whichever way the ship may roll the compass remains in a horizontal position. In a surveyor's compass the magnet is above the card, which is stationary; the needle alone moves according to direction.

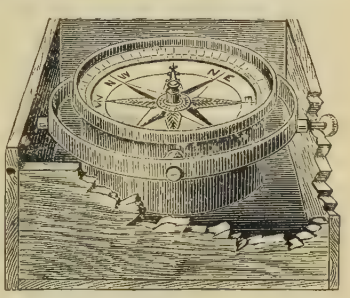


FIG. 237.—A MARINER'S COMPASS.

In order to understand why a magnet arranges itself roughly in a north and south line, we must consider polarity again. If the south pole of any bar magnet is brought near the north pole of a compass needle, the latter is attracted to it, but if the magnet's north pole is brought near the north pole of the compass, the latter is repelled or pushed away. All properly magnetised magnets and compass needles will give similar results, hence we have a most important law concerning magnetism—*there is mutual attraction between unlike poles, but mutual repulsion between like poles.* Now the earth behaves as if it contained a huge magnet extending through it, with its north magnetic pole somewhere near the geographical north pole, and the south magnetic pole near the geographical south pole. The earth's magnetic pole situated in the north possesses that kind of magnetism which attracts the so-called north pole of a compass, while the magnetic pole in the south of the earth has magnetism of the opposite kind and attracts the so-called south pole of the compass. Hence it is more correct to speak of the north-seeking pole of a magnet.

Though the magnetic and geographical poles have sometimes coincided in past times, they do not do so at present, the magnetic north being now a few degrees west of geographical north. It follows from this, that there is at any place a geographical north and south line or meridian, which may or may not coincide with the magnetic meridian. These two lines intersect, forming an angle which is called the **magnetic declination** at the places, and in navigation allowance must be made for this in order that a

course set out on a map may be followed. Maps or charts showing the magnetic declination at different parts of the world are prepared for this purpose.

THE MAGNETIC FIELD

Around any magnet, whether it be that of the earth or a small compass, there is a region in which the influence of the magnet can be experienced by other magnetic bodies, pieces of iron or steel. This region of influence is called the **magnetic field.** In the case of the earth, the field exerts its influence all over the earth's surface, so that a compass anywhere sets itself according to magnetic north and south. It should also be noted that the earth's influence is *directive* only; the compass is not pulled towards one part of the earth, since both ends of a small magnet are practically at the same distance from the earth's magnetic poles. In the case of an ordinary bar magnet, the extent of the field or region of influence depends upon the strength of the magnet and upon the nature of the substances or media surrounding the magnet. The stronger the magnet the more extensive the field, and substances like sheet iron which absorb magnetic influence produce non-magnetic gaps or **neutral spaces** in the region around a magnet.

The effect produced when a piece of iron is brought within the magnetic field is of the greatest importance in connection with the working of modern electro-magnetic machinery. A lump of iron (or steel) placed near a magnet arranges its molecules in orderly fashion and acts as a magnet itself, even though it is not touching the influencing magnet. The iron is then said to be magnetised by **induction** or influence, and the magnetism will last only so long as the iron is within the field of the inducing magnet. Should the inducing magnetism be cut off suddenly, the induced magnetism in the lump of iron instantly disappears, and this is exactly what happens in certain electrical machines we shall consider presently.

ELECTRO-MAGNETIC APPLIANCES

A wire along which an electric current is flowing has a magnetic field and acts as a magnet. For the present we cannot

discuss the nature of electricity itself, but must accept the fact that electricity is something obtained from a battery or other source and that it can be conducted along copper or other metallic wires. In any battery, such as those used in flash lamps or in wireless sets, there are two terminals, one marked with a + and called positive, the other marked – and called negative. Now if these two terminals are connected by a wire, a current of electricity flows along the wire from the positive to the negative terminal.

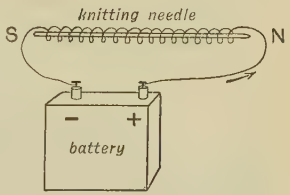


Fig. 238.
How a piece of steel may be magnetised by an electric current.

When a wire carrying an electric current is held near a compass needle the compass is deflected to one side each time the current is started, and which way the compass needle moves depends upon the direction of the current along the wire. Thus this wire, although composed of copper, has a magnetic field around it so long as the current flows; directly the current stops, the magnetic field disappears. The ordinary electric telegraph is a magnetic needle influenced by the starting and stopping of a current. The rule formulated by both Ampère and Oersted, states that, *if you imagine yourself flowing with the current and facing the compass needle, its north pole will be deflected to the left.*

The magnetic field of a current can be used for other purposes. If a yard of wire covered with cotton or other material used to prevent the wire in the coils from touching one another is wound round a steel knitting needle as shown in the illustration (Fig. 238), and then the ends of the wire connected to the terminals of a battery, so that a current flows along the coil of wire, the needle will be magnetised and the polarity will be according to Ampère's rule. In this case the needle is magnetised by induction, but the inducing magnetism is due to electricity and not to an ordinary steel magnet. The needle, being steel, will retain its magnetism; and this method provides us with an easy way of making magnets. If a bar of soft iron is used in place of the knitting needle, it will remain a magnet only so long as the current flows.

Thus, a coil of covered wire wound around an iron bar makes an arrangement in which we can develop or destroy magnetism at will, merely by starting and stopping a current flowing along the wire. Such arrangements, known as **electro-magnets,** are of the greatest use in daily life, one of the simplest and most widely used appliance having an electro-magnet being the ordinary **electric bell** (Fig. 239). In this the electro-magnet is of the 'horseshoe' pattern and consists of two pieces of iron connected by a cross-bar. The covered wire is wound first around one of these pieces of iron and then without being broken it is wound in the opposite direction around the other piece. This reversal of the wiring ensures that the outer end of one piece is a north pole and that of the other piece is a south pole, an arrangement similar in this respect to the ordinary steel horseshoe magnets sold in toy shops.

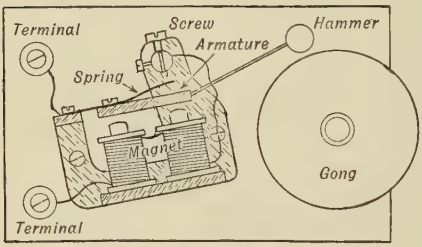


FIG. 239.—AN ELECTRIC BELL.

The polarity of the ends of an electro-magnet depends upon the direction of the winding and upon the direction of the current flowing along the wire. In the working of an electric bell, and in that of many other appliances, it does not matter which pole is north or south, and this means that it is immaterial which way the current flows. Facing the poles of the electro-magnet is a flat piece of iron connected to a rod and hammer which strikes the gong when the iron piece is pulled over towards the magnet directly the current commences to flow. But if the current continues to flow the iron piece is held there, and the gong is hit only once.

An arrangement for starting and stopping the current in rapid succession is necessary if the bell is to continue ringing. Such an arrangement is termed a *make and break*, since it repeatedly makes and breaks the pathway traversed by the current, and a current will flow only as long as the pathway or **circuit** is unbroken. The moving iron piece, technically known as an

armature, is also connected to a horizontal spring against which the point of a screw presses when the bell is not in use. This screw and spring form part of the circuit for the current.

A person operating the bell ' push ' bridges another gap in the distant part of the circuit, so that electricity flows along the wires and reaches the bell ; the magnet then pulls over the armature

FIG. 240.—WITTON-KRAMER CIRCULAR LIFTING MAGNET ON OVERHEAD TRAVELLING CRANE, HANDLING PIG-IRON.
(By courtesy of Witton-Kramer Works.)

and in doing so causes a gap between the screw and spring. The circuit being thus broken the current stops, the magnetism of the electro-magnet disappears, and the armature actuated by the spring moves quickly back to its first position, whereupon the screw again touches the spring, the current flows once more, and the whole process is repeated.

Electro-magnets of large size and power are used for picking

up and transporting iron and scrap-iron in engineering and other works (Fig. 240), while others of special construction are employed in surgery for the removal of iron and steel objects embedded in the body.

THE PRINCIPLE OF THE DYNAMO

Magnetism can be produced by means of current electricity, and the converse is equally true and important: electric currents can be produced by the influence of magnetism. These electro-magnetic machines which supply current for our domestic use,

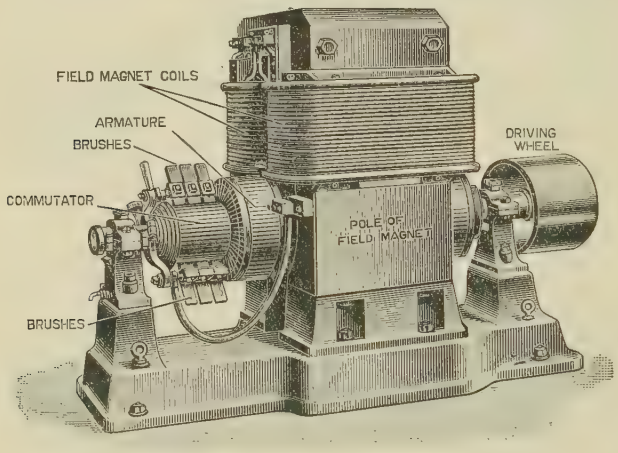


Fig. 241.—A Dynamo.

public traction, etc., are the result of the work of one of the great outstanding scientific figures of the nineteenth century. **Michael Faraday,** the son of a London blacksmith, started life as an errand boy and carried out many experiments on magnetism at the Royal Institution, of which he eventually became director.

The electric currents obtained from batteries are feeble compared with those obtained from **dynamos** or machines in which electricity is generated by the influence of magnetic fields (Fig. 241). The principle of the dynamo can be stated very simply. If a complete loop of wire is placed near, that is, within the field

of, a magnet, no electric current is produced so long as both the loop and the magnet remain at rest. But should either of them move relative to the other, the magnetic influence exerted upon the loop of wire varies, and this *variation in intensity* of a magnetic field produces electric currents in the loop of wire. As the wire moves nearer to or farther from the magnetic pole, the magnetic field influencing it increases or decreases, and the quicker the rate at which this variation can be produced the greater is the electrical effect within the wire.

A very simple kind of dynamo called a **magneto** consists of a steel horseshoe type of magnet with a rotating coil of covered

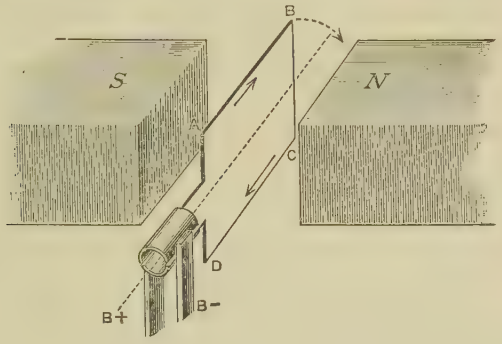


FIG. 242.—DIAGRAM ILLUSTRATING THE PRINCIPLE OF A DIRECT CURRENT DYNAMO.
THE ARMATURE IS REPRESENTED BY A SINGLE LOOP.

wire placed between the two poles of the magnet. Magnetos are used chiefly on motor cars for the production of electricity necessary for firing the gases in the engine. The motor engine, of course, supplies the power for making the coil of wire rotate in the magnetic field, only a small fraction of the total engine power being required for this purpose. The movable coil of wire in a magneto or dynamo is called the **armature,** and we must consider the means by which currents developed in the armature can be taken by wires to other places and made to do useful work, such as house lighting, heating, the operation of trams, railways, etc.

The arrangement for taking off the current is placed on the

axle of the armature, and generally consists of metallic rings upon which pieces of metallic gauze called **brushes** press so that a good contact is produced (Fig. 243). Wires connected to these brushes conduct the current to the place or places where work is to be performed.

The armature of any dynamo contains many turns of wire, and the mode of wiring is usually complicated, but the function of an armature can be understood by the consideration of one turn of wire only (Fig. 242). As the loop makes one complete rotation it passes twice through the vertical position of maximum magnetic influence (as figured), and twice through the horizontal position of minimum influence, and further, the part of the loop that was uppermost (AB) during the first half of the rotation is underneath during the remainder of the rotation. During the first half rotation the upper part of the loop proceeds from a south magnetic pole towards a north pole, but in the other half rotation it proceeds from a north pole towards a south pole. Corresponding changes occur in the other half of the loop. The result of this is that during one complete rotation two distinct currents, first flowing one way in the loop, then in the other direction, are produced.

Such currents which rapidly change their direction are said to be **alternating**. What is true for a single loop is true for all the windings of an armature, the currents are always alternating.

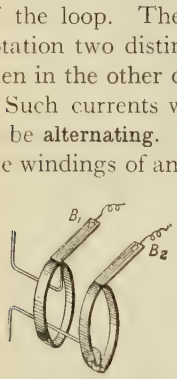


FIG. 243.—SLIP RINGS AND BRUSHES FOR TAKING OFF THE CURRENTS FROM AN ALTERNATING TYPE OF DYNAMO.

If each end of the loop is taken to a separate metal ring on the axle, the electricity is taken off by the brushes as an **alternating current** and the machine is then known as an **alternator** (Fig. 243). At the present time much electricity of the alternating type is used for house lighting, domestic purposes, tramcars and railways, but in such cases the motors of trams, etc., must be wound in such a way as to function with alternating current.

For some purposes, the charging of accumulators for example, alternating current cannot be employed, hence the use of dynamos constructed to give a *direct* current, that is, a current which flows

always in the same direction. On the axle of a direct-current dynamo is an arrangement called a **split ring commutator** or current reverser. If the armature were a simple loop, this would consist of two almost semicircular pieces of metal separated by slight gaps and each connected to an end of the loop (Fig. 242). Each piece is positive during one half of a rotation and negative during the other half. It happens that when one piece is positive, or sending the current out to the external wires, it touches that brush which always remains positive, then during the other half of the rotation the other piece of metal becomes positive and comes in contact with the *same* brush. By this means the current which is alternating in the armature is passed to the external wires and machinery as a one-direction current. In a complicated modern dynamo the armature consists of many distinct loops and windings, each communicating with a metallic segment forming part of a much divided ring on the axle.

Can the electricity generated in a dynamo be used to strengthen the magnetism of the magnets ? This is exactly what is done, of course iron being used for the field magnets instead of steel as in a magneto. Wires are taken from the armature and passed around the magnets, and dynamos differ in design according to whether all or part of the electricity available is to be passed around the field magnets. Dynamo design is beyond the scope of this book, but it may be said that most machines in common use are constructed so that part of the available electricity is used for exciting the magnets.

THE ELECTRIC MOTOR

Apart from slight modification, **electric motors** are very similar to dynamos ; in fact, if a current be passed through the windings of a dynamo it will function as a motor. But in practice it is better to construct a machine for use either as a dynamo or as a motor. In a dynamo, power from some source, steam, gas, petrol, or water, causes an armature to rotate with the result that electricity is produced, but in a motor electricity is passed through the machine, with the result that the armature rotates and its motion may be used to operate other machinery. The armature

is caused to rotate by the strong forces of attraction and repulsion developed within the magnetic field. A motor, then, has precisely the same parts as a dynamo—field magnets, armature, split ring commutator and brushes. One very important fact concerning motors must not be overlooked. The armature is rotating in a magnetic field and there is a tendency for the machine to act as a dynamo setting up a current in opposition to

FIG. 244.—ELECTRIC CAR USED AT LARGE RAILWAY STATIONS.
(By courtesy of Electricars Ltd.)

that causing its rotation. This means that the current operating the machine as a motor must be considerably stronger than any opposing current the armature could generate.

The part played by electric motors in commercial and domestic life is enormous. Large motors are used for the propulsion of electric trains and trams and for the operation of machinery in factories, while small ones are used for fans, vacuum cleaners, sewing machines, etc. In a **vacuum cleaner** a fan worked by the

motor rotates in a nearly closed space, thus causing a current of air to pass through the machine into a bag. Dust and dirt are taken with the air into this bag, the material of which is porous, allowing the air to pass out, but not the dust, etc.

THE TELEPHONE

A most useful instrument making use of the interrelation of magnetic fields and electric currents is the **telephone.** We shall understand the working of this instrument if we consider the simple arrangement invented by **Bell** many years ago (Fig. 245).

One end of a steel magnet supplies a magnetic field which influences a coil of covered wire wound around it. The ends of this wire go to terminals connected to the line wires which similarly connect with a similar telephone at the other end of the line. A little in front of the magnetic pole is a flat thin

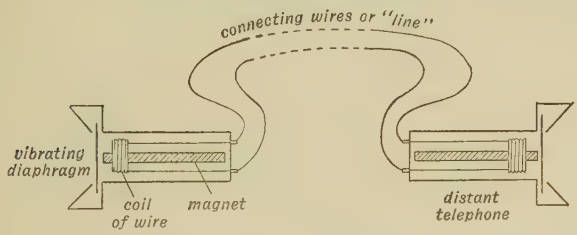


FIG. 245.—THE BELL TELEPHONE.

iron disc, which is made to vibrate by the sound waves produced by a person speaking into the mouthpiece. The vibration of this disc causes corresponding vibrations in the magnetic field influencing the coil of wire, with the result that fluctuating electric currents are set up in the wire and line. These currents produce similar variations in the magnetic field of the distant telephone, with the result that the disc there vibrates exactly as does the disc at the transmitting end, and the sounds of the voice are faithfully reproduced.

If the line is very long the electric currents are very much weakened, hence in modern telephony a current is supplied by a battery and the sounds are reproduced because the current is

modified in accordance with the variation in the magnetic field of the telephone ; in other words, variations are imposed upon the current from the battery. Loud speakers used for wireless reception are merely large telephones and work in a similar manner, the current delivered by the wireless set causing the disc or diaphragm of the speaker to reproduce certain sounds.

A telephone is operated by variations in the strength of an electric current, and these variations may be produced by other means. In the **carbon microphone,** a carbon-rod (or granules in some forms of telephone) makes loose contact with adjoining parts of the circuit, and under the influence of the voice or music the contact becomes better or worse as the case may be, and these variations in contact produce the required variations in the current operating the distant telephone.

Other instruments employing the influence of electric currents on magnets are certain kinds of meters for measuring electrical energy. These will be considered later.

CHAPTER XXVIII

OTHER KINDS OF WORK A CURRENT CAN DO

Electricity in flowing along metallic or other substances meets with a certain amount of opposition called **resistance.** Some substances offer much greater opposition than others; those, such as metals and carbon, which make relatively slight resistance, being called conductors, while materials such as rubber, silk, glass, porcelain, and mica offer such a high resistance that practically no electricity passes at all, hence they are known as **non-conductors** or **insulators.** A silk or rubber covering on a wire insulates or shuts off the electricity in the wire from the surrounding objects. For the same reason protective rubber gloves are sometimes worn by electricians when repairing overhead tram-wires or other electric mains. When, however, they are working on a high wooden ladder or stand, the structure itself is often a sufficient insulator. Pieces of porcelain are used to insulate telephone wires, wireless aerials, etc., and mica is employed to separate certain parts of electrical machines. Since water conducts electricity *if the voltage is high*, these insulators function properly only when they are kept free from moisture. Soot, a form of carbon obtained from the smoke of chimneys, is also a conductor, so that the insulators of a wireless aerial should be cleaned periodically if best results are to be obtained.

HEATING AND LIGHTING

Even the better conductors, such as copper and mercury, offer some resistance, but certain other materials, while allowing a current to pass, offer sufficient resistance to cause a large amount of heat to be produced as the result of the conflict between the conducting substance and the electricity being forced along it.

Certain metals, usually alloys, such as platinoid and german silver, offer just the correct degree of resistance for wires composed of these materials to become red hot when electricity at the right pressure is being passed along them. Electric cooking stoves, flat irons (Fig. 246), and so-called 'electric fires' for heating rooms (Fig. 247), all use high resistance wires which become red hot when the electricity is switched on. These wires are of course insulated from the metal framework of the stove, iron, or heater as the case may be.

In some electric cookers the boiling plates used for kettles, saucepans, etc., consist of wires embedded in oxide of mag-

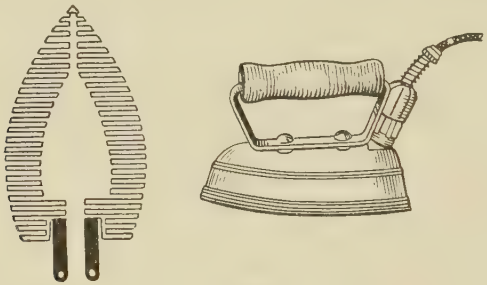


FIG. 246.—AN ELECTRIC IRON
AND ITS 'ELEMENT' OR WIRE WHICH BECOMES HEATED BY THE CURRENT.

nesium and completely covered by an outer casing so that water and grease cannot spoil the wires. This type of boiling plate retains its heat for a long time after the current has been switched off and is therefore economical. In electric fires of the 'bowl' type the resistance wire or *element* is placed in the position of the principal focus of a curved polished metallic reflector, so that the heat is projected better into the room.

Another practical application of the heating effect of an electric current is the use of thin fuse wires composed of pure tin which melts if the current is too strong, and thus breaking the circuit or pathway of the electricity, stops the current and prevents the overheating of conducting wires which might cause a fire. (Fig. 248.) The circuit of every house supplied with electricity contains a porcelain box fitted with several fuse wires each of

which controls the current in a certain part of the building, and one, the main fuse, controls the current entering the house from the external main wires.

Both electricity and heat can perform work, and there is a definite relation between them, or more correctly, there is a relation between all three, electricity, heat, and work. The connection of heat and work has been described in a previous chapter (XIX).

The amount of heat developed in a given resistance wire, for example that of a small bowl fire, depends upon three things:

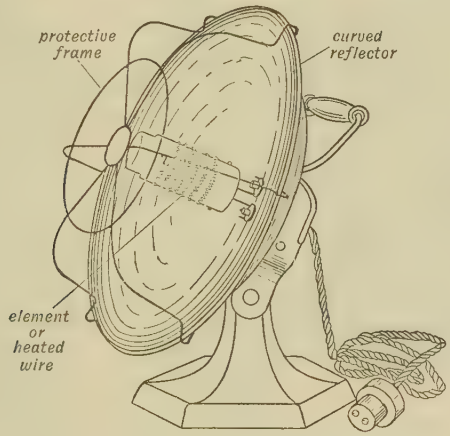


FIG. 247.—AN ELECTRIC BOWL FIRE.
THE HEATED WIRE IS SITUATED NEAR THE PRINCIPAL FOCUS OF A CURVED REFLECTOR.

(1) the resistance of the wire, (2) the time the current is allowed to flow, and (3) the square of the current strength. The first two factors are fairly obvious, but a word of explanation may be necessary concerning the third. If there are two different currents available, one just double the strength of the other, then this stronger current will develop not twice, but four times as much heat as the other in the same time and with the same resistance wire. These facts can be demonstrated experimentally by quite a simple apparatus. A definite volume of water at a certain initial temperature is placed in a glass vessel, which also

contains a covered wire having a definite resistance, and a thermometer. The rise in temperature of the water will be directly proportional to the amount of heat developed in the resistance wire. By using currents of different strengths and wires of different resistances, and by noting the time in seconds and the rise in temperature in each case, the facts stated above can be proved.

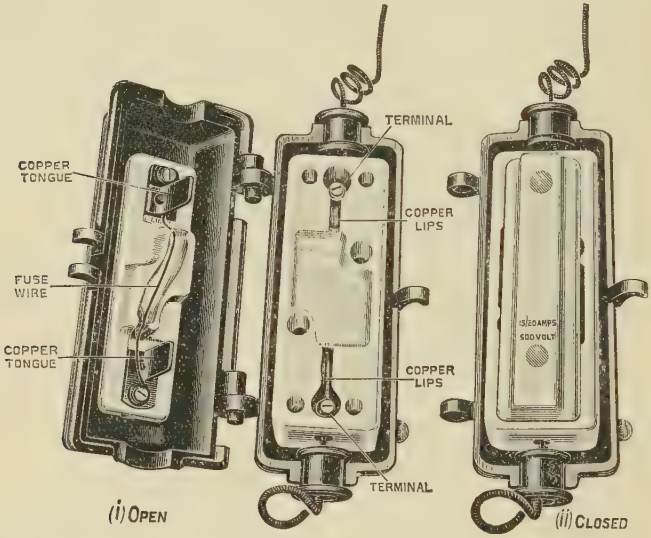


FIG. 248.—AN ELECTRIC FUSE WIRE AND ITS CONTAINING BOX.

If the heat developed is sufficient to render a wire white hot or incandescent, light as well as heat is emitted. This is the principle of the ordinary electric lamp in which a thin wire or filament is strongly heated by the passage of electricity. (Fig. 249.) The wire is thin, because such wires offer much greater resistance than thicker ones, and considerable resistance is necessary if the wire is to become luminous. The nature of the substance forming the filament also has some influence on the resistance, and in general the resistance increases as the temperature rises. The earliest electric lamp invented by **Edison**

many years ago employed a thin carbon filament, but now certain metals, particularly **tungsten,** obtained from a mineral called **wolfram,** and **tantalum,** obtained from **tantalite,** are in common use, though for some purposes carbon filaments are still employed.

FIG. 249.—AN INCANDESCENT ELECTRIC LAMP HAVING A METALLIC FILAMENT.

In order that metallic filaments shall not oxidise or rust, oxygen must be removed by pumping out the air, or as is more often the case now, some inert gas such as nitrogen and other gases present in the atmosphere occupy the space instead of air. Such lamps are said to be *gas filled.* The amount of electrical energy consumed by lamps of various sizes is discussed in Chapter XXX. Though lamps of the incandescent filament type are now much more used for street lighting than formerly, a large and powerful street light known as an **arc lamp** makes use of an intensely luminous stream of heated carbon particles traversing a small gap between two rods of carbon. The stream of conducting particles extends in a curved line or arc from one carbon to the other, hence the name arc lamp. The carbons are slowly consumed, necessitating periodic renewal, and the lamp itself is obliged to contain some automatic electro-magnetic device for bringing the carbon rods nearer together again when the gap becomes too large and the light is extinguished. When alternating current is used the two rods are consumed at the same rate, but if direct or one-way current is employed, the positive rod wears away at a greater rate than the other, since the stream of incandescent particles is always in one direction from the positive to the negative rod.

FIG. 250.—AN ELECTRIC ARC LAMP USED FOR STREET LIGHTING, ETC.

The carbon arc lamp, on account of the **ultra-violet rays**

emitted by it, is of considerable importance in modern medical practice. These rays have a marked tonic effect in cases of nervous debility and yield beneficial results in a large number of other diseases and disorders. The patient sits or lies in the

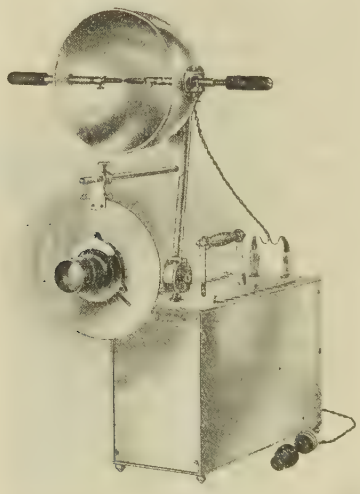


FIG. 251.—AN ARC LAMP USED FOR THE MEDICINAL APPLICATION OF ULTRA-VIOLET RAYS.
(By courtesy of Messrs. Ajax Ltd.)

glare from an arc lamp, placed at a definite distance, and the dose varies from one or two to several minutes. Since ultra-violet rays are injurious to the eyes, protective glasses must be worn.

ELECTROLYSIS AND ELECTRO-PLATING

An electric current can perform chemical work. If some crystals of copper sulphate, commonly called blue vitriol, are dissolved in water a blue solution is obtained from which the copper can be liberated by passing a current through it. The solution should be filtered and placed in a suitable vessel such

as a glass or earthenware pot. A piece of thin sheet copper is attached by a wire to the *positive* terminal of a battery or accumulator, while some object, say an old spoon, to be plated with copper, is similarly connected to the *negative* terminal of the battery. (Fig. 252.) The copper and the spoon are then placed in the solution near each other but not touching, and after a time a thin covering of copper appears on the spoon. The copper deposited comes from the solution and an exactly equivalent weight of metal from the sheet metal goes into the solution, which thus holds the same amount of copper sulphate as long as any of the sheet copper is left.

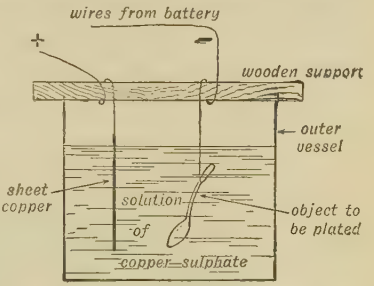


FIG. 252.—DIAGRAM REPRESENTING THE APPARATUS REQUIRED FOR COPPER PLATING AN OBJECT.

How is this transference of metal brought about? The electricity traverses the solution, but not in the same way as it passes along a piece of wire. Copper sulphate is composed of copper, sulphur, and oxygen combined together in the proportions represented by the chemical formula $CuSO_4$, where Cu stands for copper, S for sulphur, and O_4 for four atoms of oxygen. (Fig. 253.) The copper and sulphur are each present as one atom. Hence one extremely small particle, or molecule as it is termed, of copper sulphate contains an atom of copper, an atom of sulphur, and four atoms of oxygen.

The electric current is passed into the solution by the sheet copper and out of it by way of the spoon, and while this current is passing, the copper sulphate in solution may be regarded as consisting of two portions, or **ions**—copper, which is an **electro positive ion**, and the remaining sulphur and oxygen which together form an **electro negative ion.** Ions differ from ordinary atoms and molecules in that *they possess charges of electricity*. Thus an ion of copper is an atom of copper having a charge of positive electricity, and the remaining SO_4 group differs from a mere chemical combination of sulphur and oxygen in having a

charge of negative electricity. In a molecule of copper sulphate the two ions being together are properly balanced, the negative and positive mutually satisfying each other. But when the electricity is passed through the solution the sheet of copper attached to the positive plate of the battery attracts the negative SO_4 ions near it, and this sets free from the neighbouring molecules an equivalent number of positive copper ions which in their turn capture the negative ions of the other copper sulphate molecules near by, and so on through the solution. Finally, at the farther end some liberated copper ions yield up their electricity and as ordinary atoms of copper are then deposited on the spoon.

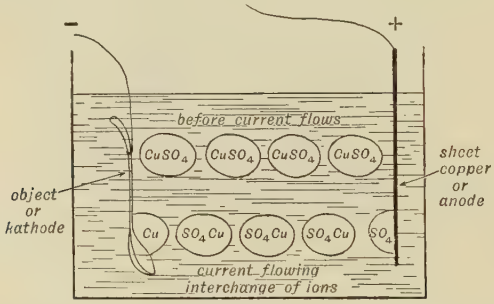


FIG. 253.—DIAGRAM REPRESENTING THE INTERCHANGE OF IONS WHEN AN ELECTRIC CURRENT PASSES THROUGH A SOLUTION OF COPPER SULPHATE.

This interchange of ions is illustrated diagrammatically in Fig. 253, but it must be realised that only a few of the vast number of ions can be represented. A solution which conducts electricity by this interchange of ions is called an **electrolyte**, and the process is known as **electrolysis**. The sheet of metal by which the current enters the electrolyte is called the **anode**, and that by which the current leaves the solution is termed the **cathode**. When objects are to be plated with a metal the anode must be a piece of the metal in question, the object to be plated forms the cathode, and the electrolyte must be a solution containing a soluble compound of the desired metal. Thus in silver plating, silver is the anode and a substance such as silver nitrate or cyanide is dissolved to

form the electrolyte. In actual practice a fairly strong current is used, and all objects to be plated must be thoroughly cleaned of grease and dirt before they can be submitted to the process. Many large objects are **nickel-plated,** and smaller articles of jewellery are similarly covered with a thin layer of gold.

There is a definite relation between the strength of the electric current, the time it flows through the electrolyte, and the weight of metal deposited on the object being plated. This quantitative relation was first investigated by the famous Victorian physicist, **Faraday,** to whom we are also indebted for much of our knowledge concerning induced currents and the connection between magnetism and current electricity. **Faraday's laws of electrolysis** state (1) that the weight of any ion liberated, metal or otherwise, in a given time is directly proportional to the strength of the current, (2) with a current of given strength the weight of ion set free is directly proportional to the time the current flows, and (3) if the same current is passed through several different electrolytes the amount of chemical work done in one of them is equivalent to that done in any of the others. This last rule needs a little explanation. Chemically, 31·5 grammes of copper are equivalent to 108 grammes of silver, so that if the same current is passed through a solution of copper sulphate, and then through one containing silver nitrate, 31·5 gm. of copper are deposited in exactly the same time as 108 gm. of silver.

The relation between the current strength and the weight of metal deposited affords a very delicate and accurate mode of measuring the strength of a current, and a definition of the unit of current strength as found by this method is given in Chapter XXX.

Electro-plating is by no means the only practical application of electrolysis to metallurgical processes. Certain metals, particularly **potassium, sodium,** and **aluminium,** are obtained by passing powerful currents from a dynamo through suitable electrolytes. In these cases the electrolytes are not solutions in water, since water reacts violently with both potassium and sodium. The chief source of aluminium is a natural clay known as **bauxite.** Potassium and sodium are obtained by electrolysis of the fused hydroxide of each metal. A hydroxide

contains hydrogen and oxygen, besides the metal, and the ions liberated will be the metal and hydrogen at one end and the oxygen at the other. In another process fused salt or sodium chloride is electrolysed to obtain sodium, and in this case chlorine, a gas used in the preparation of bleaching powder and for other purposes, is also obtained.

In addition to the deposit or extraction of metals, electrolysis is very useful in many other ways. The hydroxides mentioned above are examples of *alkaline* substances, but some acids also form good electrolytes. If a little sulphuric acid is added to water, and a current passed through the solution, the ions liberated are hydrogen at the cathode and the SO_4 group at the anode, but the SO_4 cannot exist as a separate substance, so it reacts with the water taking hydrogen with which to form new molecules of sulphuric acid, and the oxygen of this water appears as a substance liberated at the anode. Thus, the substances which can be collected by the electrolysis of dilute sulphuric acid are hydrogen and oxygen, and the apparatus in which this is usually done is called a **voltameter** (Fig. 254). Since water consists of two volumes of hydrogen combined with one volume of oxygen, the volume of hydrogen collected in a given time will be twice that of the volume of oxygen. A very important practical application of this particular electrolysis is the **accumulator** or secondary cell described in the next chapter.

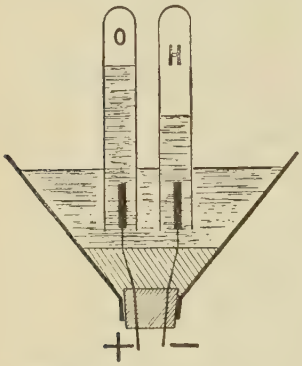


Fig. 254.—A Voltameter. Arranged for the Electrolysis of dilute Sulphuric Acid.

If hydrochloric acid is electrolysed, the ions liberated in equal volumes are hydrogen and chlorine, and this affords a method of proving the composition of hydrochloric acid by volume. It must be noted *that hydrogen and metals always appear at the cathode*, and this fact affords a simple mode of testing the polarity of a battery or of a wire carrying a current. If such a wire is cut

and the two ends are kept a little apart and made to touch a piece of porous paper soaked with **potassium iodide** solution, a brown stain occurs on the paper near the positive wire where **iodine,** a non-metal, is being liberated by electrolysis.

In the treatment of some diseases, the application of iodine or some other ion is effected by an electrolytic process, the iodine being liberated and absorbed at the spot where the positive electrode is in contact with the patient.

CHAPTER XXIX

ACCUMULATORS AND VOLTAIC CELLS

As we have seen, an electric current can do very useful work of a chemical nature, and now we will consider the converse process, that of chemical work producing an electric current. A form of battery well known now on account of wireless apparatus is an **accumulator** which consists of several lead plates and dilute acid contained in a celluloid or glass case.

Though accumulators are not the simplest forms of apparatus for converting chemical energy into electricity, it is better to consider these first since their operation depends upon electrolysis, the kind of chemical change that was described in the previous chapter. Many years ago it was discovered by Grove that, if the terminals of a voltameter in which acidulated water had been electrolysed were joined by a wire, a feeble current passed along the wire. As the result of chemical work done in the voltameter by a current previously passed through it, a current in the reverse direction could afterwards be obtained from it. Thus, a *voltameter after electrolysis acts as a battery*. The separated ions, oxygen and hydrogen, tend to recombine and deliver up their electricity ; even when an electric current is being passed through the solution during electrolysis there is this tendency to recombine, a fact that explains why the current from only one ordinary cell is not sufficient to electrolyse acidulated water.

In **Grove's gas battery** several simple voltameters were joined together in series, that is, in such a way that the current passed through each voltameter in turn. This meant, of course, that the resulting current obtained from the arrangement after

electrolysis was much better than that from a single voltameter. This gas battery, the pioneer of the modern accumulator, apart from giving a feeble current, had numerous other disadvantages. For example, it was too large in proportion to results obtained, and it was not portable.

Planté's cell, invented in 1860, and having plates of ordinary metallic lead immersed in diluted sulphuric acid, represented a later stage in the evolution of the accumulator. The process of charging a Planté accumulator was tedious, the charging current having to be sent for some time in one direction, then for some time in the other direction. Planté cells resembled modern accumulators in having, when charged, *the negative plate in the state of metallic lead, the other or positive plate being covered with a dark brown substance known as lead peroxide.* In a present day accumulator, used for wireless and other purposes, there are several positive plates connected together but prevented from touching a similar set of connected negative plates (Fig. 255). All the plates are immersed in dilute sulphuric acid, the whole being contained in an outer case usually composed of celluloid, or of glass in the case of large accumulators used for country house lighting, etc. Vents or small openings in the case are supplied to permit the escape of gases formed as the result of the chemical changes taking place within.

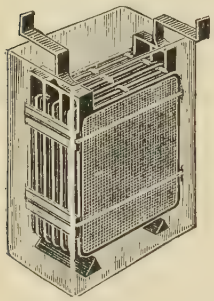


FIG. 255.
AN ACCUMULATOR.
USED FOR HOUSE LIGHTING, ETC.

As early as 1881 it was found that if the leaden plates were both coated with a layer of red powder known as **red lead** (another oxide of lead) they were more quickly brought, on charging, to the required condition. Other improvements have been introduced, so that modern plates are made in the shape of a grid having numerous square spaces which are filled with a paste of red lead (Fig. 256).

The first or initial charge given to an accumulator always takes some time and requires considerable care, hence the higher price

asked for this initial charge. The sulphuric acid employed must be of the right strength, and this is tested by determining its relative density or specific gravity by means of a hydrometer. The density alters as the accumulator is being used, so that after discharge it is about 1·18. A solution of the right strength is prepared by mixing acid with water, the mixture having a specific gravity of about 1·250

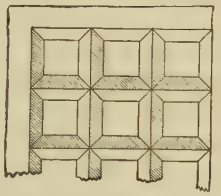


FIG. 256.—PART OF AN ACCUMULATOR PLATE SHOWING THE 'GRID' PATTERN.

It is not easy to describe in simple language the exact nature of the chemical changes which take place within an accumulator before and after discharge. While the charging current is being passed through the apparatus the ions liberated by the electrolysis are hydrogen and oxygen, the former appearing at the negative plates and reducing their surfaces to the state of soft spongy lead, while the oxygen appearing at the positive plates supplies additional oxygen required to convert the surfaces to peroxide of lead. After the accumulator has been used as a battery and has been discharged, both sets of plates are coated with a whitish substance called **lead sulphate,** and should the apparatus be allowed to stand in the discharged condition for a long time, this **sulphation** seriously damages the plates. Accumulators are kept in order by constant use and recharging.

The amount of electricity that an accumulator can yield after a single charge depends upon its capacity, and of course upon its being properly charged. The capacity depends upon the number and size of the plates, larger and more numerous plates naturally having greater capacity than smaller and fewer plates. The capacity is generally stated on the accumulator, and is expressed as so many **ampere hours.** An accumulator having a capacity of 40 ampere hours (continuous, not ignition), will yield a current of one ampere for 40 hours, or a current of $\frac{1}{2}$ ampere for 80 hours, and so on. For the ignition of gases in a motor engine the time is twice that of continuous use, since the current is used only intermittently. A more detailed description of the unit called an ampere is given in Chapter XXX, where electrical

units are discussed, and where the voltage of accumulators and batteries is also explained.

It must be clearly understood that when an accumulator is 'charged,' electricity is passed through it and *not stored in it* in the form of electricity as water can be stored in a bottle. The chemical changes brought about by the passage of the charging current are such that when later the terminals of the accumulator are connected, other chemical changes then produce a current. Accumulators, since they produce electric currents as the result of these **secondary chemical changes** due to electrolysis, are known as secondary cells, in distinction from the primary cells or batteries which yield currents due to chemical actions without previous electrolysis. Though most accumulators in common use have leaden plates immersed in sulphuric acid, there are others of recent design containing nickel plates in an alkaline paste composed of a whitish substance known as caustic soda. The operation of these is also based upon electrolysis, and the advantage is in having no fluid electrolyte that can be spilt, but the initial cost is relatively high.

PRIMARY BATTERIES USED FOR ELECTRIC BELLS, FLASH LAMPS, WIRELESS HIGH TENSION, ETC.

Quite as well known as accumulators are the small dry cells used for lighting little pocket electric lamps, ringing bells, etc., and we must now consider the construction and mode of working of these voltaic batteries.

Towards the close of the eighteenth century two Italian scientists laid the foundation of our knowledge concerning current electricity. **Galvani,** a physician, experimented upon the nervous systems of dead frogs and found that two dissimilar metals touching at one end and in contact with the frog's nerves at the other ends caused muscular contraction. **Volta,** a professor of physics, discovered that two dissimilar metals, copper and zinc, when placed in dilute sulphuric acid generated a current of electricity if the outer ends of the metals were connected by a wire.

If we are to understand the working of modern voltaic cells,

we must first examine the operation of the simple cell invented by Volta. When a piece of zinc is placed in sulphuric acid, bubbles of hydrogen, turned out of the acid, collect near and upon the zinc, but when a piece of copper is placed in the solution no action takes place between it and the acid, and the hydrogen still escapes near the zinc (Fig. 257). But if a wire now connects the upper ends of the metals the bubbles of hydrogen appear at the copper instead of near the zinc. *There is an interchange or migration of hydrogen ions towards the copper plate, thus causing it to send a current around the circuit.* Note that the solution between the two metals forms part of the circuit or pathway for the current, and that the direction of the current in the liquid is from zinc to copper.

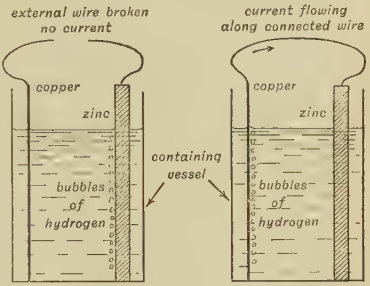


FIG. 257.—EXPLANATION OF VOLTA'S SIMPLE CELL.

The primary cause of the electrification is the chemical action between the zinc and the acid, and the electricity obtained must be regarded as equivalent to the chemical work done; chemical energy is converted to that of electricity. The action being continuous, the cell is like a pump forcing electricity around the circuit, but the action will continue only as long as there is some undissolved zinc and as long as certain other conditions are fulfilled.

This simple electric cell has several disadvantages which make it of small practical value. It is not portable, and the current obtained is weak, but the chief trouble consists of the accumulation of hydrogen on the positive or copper plate. Once the hydrogen has given up its electricity it becomes a nuisance, forming a gaseous layer that slows the action down. This slowing down, due to the accumulation of hydrogen, is known as **polarisation,** and any cell to be of practical value must have some means of preventing such accumulation.

The process of doing away with the hydrogen after it has yielded its electricity is known as **anti-polarisation.** Some early

forms of cell attempted to get rid of the hydrogen by mechanical means, such as points on the positive plate, but this required periodic shaking. In modern cells the method of anti-polarisation is chemical, the hydrogen being supplied with oxygen from some substance rich in oxygen and ready to part with some. Such substances are known as **oxidising agents,** and they oxidise the hydrogen so that water is formed, and this prevents the formation of any gaseous film on the positive plate of a cell. Though nitric acid, and a yellow substance called potassium dichromate, are sometimes used in laboratory work, practically all primary cells employed commercially and in the home contain a black powder called **manganese dioxide** which performs the work of anti-polarisation.

Two kinds of cell more widely used than any others are that invented by **Leclanché,** and the **dry** cell. In the Leclanché (Fig. 258) a solution containing dissolved sal-ammoniac or ammonium chloride corresponds to the sulphuric acid in the simple cell of Volta. A cylindrical rod of zinc is placed in this solution which then reacts with it, so that hydrogen is given off. The positive plate of the Leclanché cell consists of a rod of carbon placed in an unglazed earthenware porous pot containing the black oxide of manganese and carbon grains. This porous pot and its contents are, with the zinc, placed in a square glass vessel containing the solution of sal-ammoniac. As stated above, the zinc liberates hydrogen ions from the solution, and these proceed through the porous pot to the carbon, where they deliver up their positive electricity, after which the hydrogen is oxidised by the manganese dioxide with the production of water, which slowly collects inside the porous pot, but can be drained away if the pot is occasionally removed and allowed to stand for a time. The carbon corresponds to the copper of the simple cell. The action between the zinc and sal-ammoniac is relatively quiet, and the

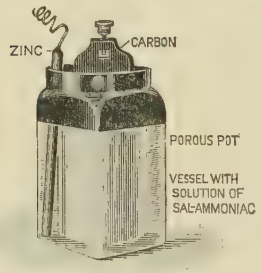


FIG. 258.—A LECLANCHÉ CELL.

metal may last a long time without being removed from the solution. This, of course, is a great advantage, and the length of life of the zinc may be increased by first cleaning it with dilute acid and then rubbing it with a little mercury.

This process is known as **amalgamation**, since a surface layer of zinc amalgam is formed. Amalgamation of zinc plates tends to prevent what is known as **local action**, or the generation of small unwanted currents in the zinc itself because of impurities in it. Antipolarisation in a Leclanché cell is fairly good, but the cell is most useful in connection with electric bells where an intermittent current only is required. An improved apparatus known as an **agglomerate Leclanché cell** dispenses with the porous pot, the manganese dioxide and powdered carbon being cemented to a

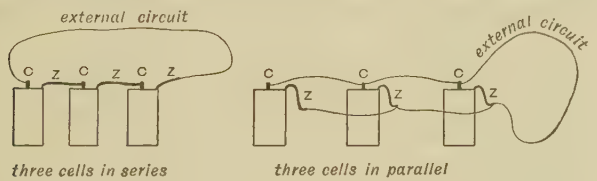


FIG. 259.—ELECTRIC CELLS ARRANGED IN SERIES AND IN PARALLEL.

C = CARBON. Z = ZINC.

compact mass placed outside of the carbon plate and kept in place by rubber bands. A better current is obtained, because the porous pot of the ordinary cell offers a resistance to the electric current.

Though a discussion of voltage is left for the next chapter, it may be as well to mention that the voltage of a single Leclanché cell is about 1·6 volts at first, but if the current is allowed to flow for some time, the voltage falls below this. If two cells, Leclanché or any other type, are connected together by joining the zinc of one to the carbon terminal of the next, the arrangement gives twice the voltage of one cell, and the cells are said to be joined in **series** (Fig. 259). If the two zincs are joined together, and the two carbons connected to each other, then the cells are joined in **parallel**, an arrangement in which the voltage is only the same as that of one cell, but the current is increased. Which

mode of connection gives the better result depends upon the kind of work the current has to perform, as will be shown later.

Probably the voltaic cell in most common use is the kind known as 'dry,' since no liquid is employed (Fig. 260). Very numerous makes and sizes of dry cell are on the market, and they are employed in connection with bells, telephones, certain low consumption wireless valves, flash lamps, etc. Many of the larger cells are cylindrical in shape, the cylinder being composed of zinc which at the same time acts as the negative plate of the cell and as a containing vessel. Paper or cardboard is usually pasted over the zinc to ensure against electrical loss. In the centre of the cylinder is placed the carbon rod or positive plate which is prevented from touching the zinc at the base. A paste containing sal-ammoniac and plaster of Paris is placed next to the zinc, and the remaining space near the carbon is occupied mainly by a mixture of manganese dioxide and powdered carbon. The parts are very similar to those of the Leclanché cell, the differences being the use of a sal-ammoniac paste instead of a solution and the absence of a porous pot. In its mode of action also the dry cell is similar to that of the Leclanché, hydrogen ions proceeding from the zinc to the carbon, and the hydrogen is then oxidised by the oxide of manganese.

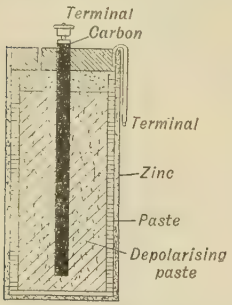


FIG. 260.—VERTICAL SECTION THROUGH A DRY CELL.

The small rather flat dry batteries sold for a few pence contain three cylindrical cells connected in series so that the total voltage is three times that of one cell, altogether about 4·5, when the battery is new. Several of these little batteries are often joined in series to obtain a supply of high tension for wireless sets, the short brass positive strip of one being joined to the longer negative strip of the next, and so on.

Another kind of cell used more in laboratories than in ordinary domestic life is known as a **Daniell's cell** (Fig. 261). In this, a rod of zinc is placed in dilute sulphuric acid contained in a cylindrical

porous pot. The porous pot and its contents are placed in a larger cylindrical copper vessel which functions both as the positive plate of the cell and as the container. The space between the porous pot and the copper vessel is occupied by a solution of copper sulphate which performs the work of anti-polarisation. But the action is not one of oxidation this time. As the hydrogen delivers its electricity to the copper it reacts with the copper sulphate turning copper out of the solution and forming sulphuric acid. The particles of copper liberated from solution adhere to the outer copper vessel, while the hydrogen converted to sulphuric acid is rendered harmless so far as polarisation is concerned. The Daniell's cell retains a steady voltage for a considerable time, but that of one cell is not more than one volt. On account of the two liquids used and the necessity of removing the zinc from the acid when not in use, this type of cell is scarcely suitable for domestic or commercial use.

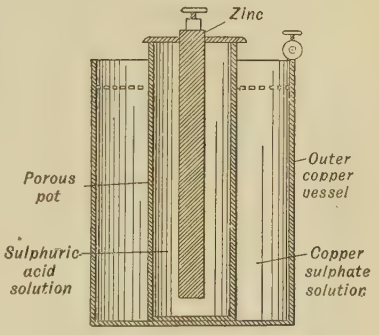


FIG. 261.—A SECTION THROUGH A DANIELL'S CELL.

Both types of cell, primary and secondary, have their respective merits and disadvantages, and much depends upon the class of work to be done. An accumulator has the advantage of yielding a larger and steadier current and it can be charged many times, but the dry cell scores in being more portable and in its low initial cost, though once used up it cannot be recharged. In all cases where accumulators are used, care must be exercised to see that the terminals are not connected by a short wire or other circuit having too low a resistance, since such ' shorting ' spoils the accumulator plates.

CHAPTER XXX

ELECTRICAL UNITS AND MEASUREMENTS

THE utility of current electricity depends chiefly upon the fact that it flows along metallic conductors or wires. What causes this flow of electricity? An answer to this question can be understood more easily if we consider the flow of water and the transference of heat, both of which are in many ways similar to the passage of electricity. Water flows from a higher to a lower level. If two tanks are connected by a pipe, water will flow from the tank where it is at the higher level into the other and will continue to flow until the water in both tanks is at the same level. Similarly if a cold object, such as a potato, is placed in a vessel containing hot water, heat will pass from the water into the potato and will continue to do so until both are at the same temperature. Temperature may be regarded as heat level. It must be clearly understood that quantity of water is not the same as water level, since a large volume of water may be at a low level, as in the case of a lake near sea-level, or a little water may be at a high level, as in a mountain stream. Water flows as the result of a *difference* in level quite apart from the quantity of water concerned. Similarly, temperature is not the same thing as quantity of heat.

THE RELATION BETWEEN VOLTAGE AND CURRENT

In electricity we have very similar characteristics. The correct name of the condition we may roughly describe as electric level is **potential**, and it is a difference of potential (P.D.) or **electromotive force** (E.M.F.) that causes a current to flow from one part of a circuit to another part. The height of a water column is measured in feet and this indicates the water pressure; similarly,

potential may be considered as electric pressure and is measured in units called **volts**. Just as water level indicates pressure and not quantity of water, so voltage indicates potential and not quantity of electricity. A small amount of electricity at a high voltage is analogous to a mountain stream, whereas a large quantity of electricity at a low voltage is similar to the water of a lowland lake.

The analogy between water and electricity can be carried a little farther. The water of a mountain stream falls until it reaches sea-level, that is, until its pressure becomes zero; similarly in any electric circuit the voltage falls to zero or no volts, and it follows from this that *the voltage is different at different parts of a circuit*. Consider the case of water of a mountain lake being conducted by pipes to a power-station lower in a valley. Of course the total pressure on the turbines in the power-house is equal to the complete head of water in the pipes, but the pressure at any point along the pipes is determined by the head of water above that point, hence the water pressure is different at different levels of the pipes. The amount of water passing through the turbines depends upon the size and number of the conducting pipes, the larger and more numerous the pipes the greater the quantity of water available in a given time. In electricity the strength of the current not only depends upon the pressure or voltage but also upon the size and kind of metallic or other conductors forming the circuit. Generally the thicker and shorter the wires the stronger the current.

The strength of an electric current is measured in units called **amperes**, and the *Board of Trade ampere is defined as being that current which will deposit* 0·001118 *gm. of silver from a solution of silver nitrate in one second by the process of electrolysis* described in Chapter XXVIII.

Wires and other conductors forming a circuit offer an opposition to the passage of electricity, and as we have seen in the previous chapter, this opposition is known as resistance. Just as narrow pipes prevent a good flow of water, so thin wires offer considerable resistance and weaken a current of electricity. The resistance also depends upon the kind of metal used, silver having less resistance than others, but copper or copper covered wires are used generally

as they are cheaper and nearly as good as silver. Other good conductors of electricity are brass, mercury, and carbon. Insulators such as rubber, porcelain, silk, glass, and mica, offer such high resistance that no current passes at all. In making comparisons of specific resistances, wires of equal length and thickness must be used. With any given metal, the resistance increases with length but decreases with thickness, and in the case of a wire of uniform thickness we have R varies as l/a, a formula in which R represents resistance, l means the length, and a is the area of cross-section.

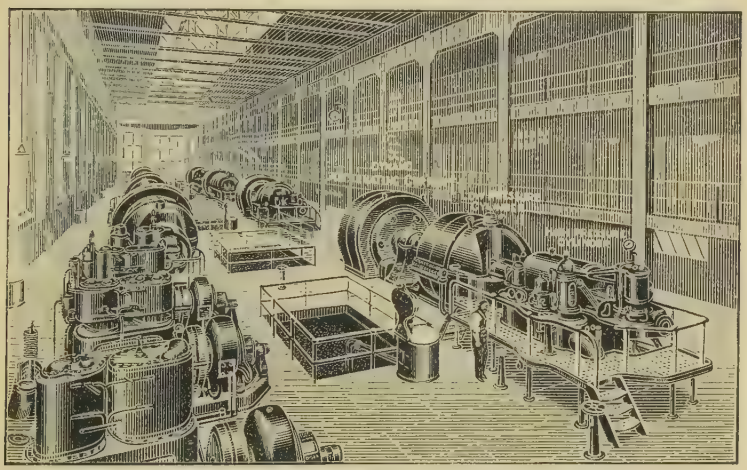


FIG. 262.—THE LOTS ROAD POWER STATION, CHELSEA, LONDON, SHOWING TURBINES COUPLED DIRECTLY TO ALTERNATORS.
(By courtesy of Messrs. C. A. Parsons Ltd., Newcastle.)

Of course carbon plates and solutions of electrolytes as used in accumulators and batteries also offer resistance, so that in any electrical circuit there is the resistance of the *external* wires and machinery denoted by the symbol R, and the *internal resistance* within the battery and represented by the symbol r. The total resistance of the complete circuit is therefore represented by $R + r$.

Calculations concerning voltage, current strength, and resistance are of great importance in electrical work of all kinds, and it is necessary to employ some unit of resistance. This unit is called an **ohm**, the name, as volt and ampere, being derived

from a pioneer of current electricity. One ohm is roughly the resistance of a piece of copper wire ten feet in length and about $\frac{1}{100}$ inch in diameter.

The relation between voltage or electromotive force (E), the resistance (R), and the resulting current strength (I) is expressed by **Ohm's Law,** which states that *the current obtained varies directly as the electromotive force and inversely as the resistance.* This expressed as a formula is $I = E/R$. Divide the E.M.F. in volts by the resistance in ohms and we obtain the current in amperes. From this it follows that one volt is that electromotive force which urges a current of one ampere along a circuit which has a resistance of one ohm. Also, it is obvious that from the equation $I = E/R$, any one of the three quantities can be calculated provided the other two are known.

Find the strength of the current when a 2 volt accumulator is used with a circuit having a resistance of 8 ohms. Here $I = \frac{2}{8} = 0{\cdot}25$ ampere. More accurately, we should include the internal resistance of the accumulator itself, and if this is 0·2 ohm, the formula is $I = \frac{E}{R + r}$, hence in this case $I = \frac{2}{8 + 0{\cdot}2} = 0{\cdot}244$ ampere, very nearly the same current, since the internal resistance of an accumulator is small. If several accumulators or cells are employed, the current obtained depends upon the way in which the cells are connected together. When the positive of one cell is connected to the negative of the next, and so on, the cells are arranged in *series* (Fig. 259), and the E.M.F. is that of the individual cells added together. But in this case the internal resistances must also be added, so that the series mode of connecting cells is suitable when the internal resistances are small compared with that of the external circuit. An example will make this clear.

Suppose that 4 cells are connected in series, each cell having a potential (E) of 2 volts and an internal resistance (r) of 0·2 ohm, the external circuit having a resistance (R) of 10 ohms. The current obtained will be according to the formula :

$$I = \frac{E_1 + E_2 + E_3 + E_4}{R + 4r} = \frac{8}{10 + 0{\cdot}8} = \frac{8}{10{\cdot}8}$$

$= 0{\cdot}74$ of an ampere, approx.

But if the same cells are joined in *parallel* by connecting all the positive plates together and all the negative plates together, the voltage is only the same as that of one cell, but the total internal resistance is only $\frac{1}{4}$ that of one cell. It is the same as if we had one large cell with plates 4 times the size of those in one of the small cells. Hence in this case the formula is :

$$I = \frac{E}{R + \frac{r}{4}} = \frac{2}{10 + \frac{0{\cdot}2}{4}} = \frac{2}{10{\cdot}05} = 0{\cdot}2 \text{ of an ampere approx.}$$

The parallel method of connecting cells is better when the external resistance is small. Thus, with the cells as above, but the resistance of the external only 0·5 ohm, we have :

$$I = \frac{2}{0{\cdot}5 + 0{\cdot}05} = 3{\cdot}7 \text{ amperes.}$$

In most practical applications—bell and telephone circuits, the lighting of small lamps, electrolysis, etc.—it is usual to connect cells in series, since considerable lengths of wire, very thin filaments of lamps, and electrolytes all offer considerable resistance. A four volt accumulator really consists of two separate 2 volt cells connected in series.

We must now consider the results obtained when wires forming the external circuit are arranged in different ways, since different arrangements of the same wires alter the resistance R. Take first the simple case of a single 2 volt cell sending a current along a single copper wire of uniform thickness. Certain fundamental facts should be remembered — (1) the resistance is the same at all parts of the external circuit, and from this it follows that (2) the voltage falls uniformly along the circuit, and (3) the current strength is the same at all parts of an unbranched circuit.

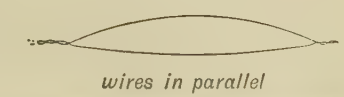


FIG. 263.—CONDUCTORS ARRANGED IN SERIES AND IN PARALLEL.

But if we have two wires, each having a resistance of say 5

ohms, we can arrange them in two distinct ways: in series, that is one after the other, forming an unbranched circuit, or in parallel forming a branched circuit as shown in the diagram. (Fig. 263).

When these conductors are joined in series the resistances must be added, but when they are in parallel, there is a better pathway for the current and the resistance of the two wires taken together is only half that of one of them. In the series arrangement R = 10 ohms, but with the wires in parallel R = 2·5 ohms, hence if the internal resistance of the cell is ignored, the parallel arrangement gives in this case four times as much current as the series arrangement. Here is a practical example. Compare the currents obtained when two electric lamps, each having a resistance of 400 ohms, are connected in series and in parallel, the E.M.F. of the mains being 200 volts. According to Ohm's Law, either lamp used by itself passes 0·5 ampere.

With the lamps in series we have:

$$I = \frac{200}{400 + 400} = \frac{200}{800} = 0{\cdot}25 \text{ ampere.}$$

The total current is only half that passed by either lamp used singly.

When they are in parallel:

$$I = \frac{200}{\frac{400}{2}} = \frac{200}{200} = 1 \text{ ampere.}$$

In this case each part of the branched circuit has the same resistance and each takes 0·5 ampere, but when the resistances are unequal, the portion of the total current taken by each branch depends upon its relative resistance, that wire having the higher resistance taking a smaller portion of the current than the other. Thus, supposing a wire having a resistance of 3 ohms is joined in parallel with one of 1 ohm, then, whatever the total current may be, the 3 ohm wire takes only $\frac{1}{4}$ of it, while the 1 ohm wire takes the other $\frac{3}{4}$. The same rule applies to any number of branches in a complex circuit, the pathway having least resistance carries more current than any one of the others.

It follows from the relation between resistance and current that wires of high resistance can be employed to cut down the current when desired, as in the control of tramcars and electric railways. The driver of a tramcar or train regulates the speed by switching in or out various resistances so that the current working the motors

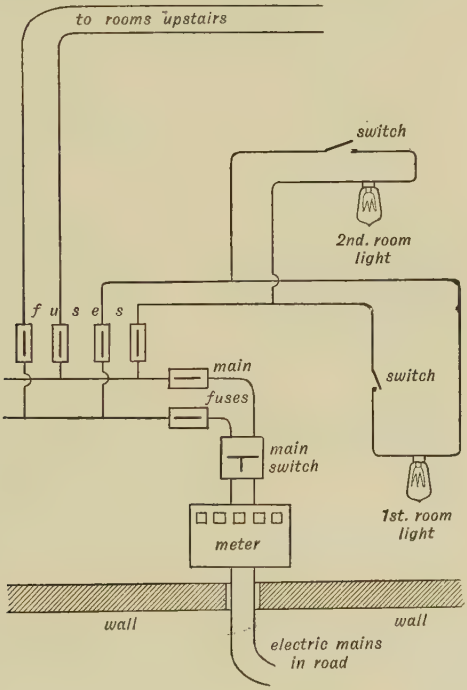


FIG. 264.—GENERAL PLAN OF WIRING OF A HOUSE FOR ELECTRIC LIGHT.

NOTE THAT CONNECTIONS ARE ALL IN PARALLEL, OTHERWISE SWITCHING OFF ONE LAMP WOULD SWITCH OFF THE WHOLE.

is correspondingly varied. These resistances are composed of metal (nickel-chrome) having a relatively high resistance and coiled so that a considerable length can be placed in a small space. Valves for wireless reception and many other forms of electrical apparatus are also controlled by adjustable resistances.

POWER CONSUMPTION AND ELECTRIC METERS

In the examples given above it is shown that the current obtained is greater when two lamps in parallel are used instead of one, and of course the consumer has to pay for the extra current used. If the lamps were joined in series the current would be reduced and the necessary degree of illumination would not be obtained. The electrical energy consumed in lighting, heating, or in any other form, depends upon both the voltage and the current used. Electrical power is measured in units called **watts,** and the number of watts is found by multiplying the volts by the amperes. Thus, if 200 volts are urging a current of 5 amperes along a circuit, the number of watts is 1000, or one **kilowatt.** If this current continues at the same voltage for one hour the energy consumed is a **kilowatt-hour,** or one **Board of Trade unit of power** This is the unit employed in the measurement of domestic and commercial electrical consumption, but various prices are charged by different local power companies. Both industry and domestic work will benefit considerably when the supply of electricity becomes more centralised and produced at a cheap uniform rate. As a rule a higher rate is charged for lighting than for heating, cooking, and other forms of power consumption, and two separate meters are used.

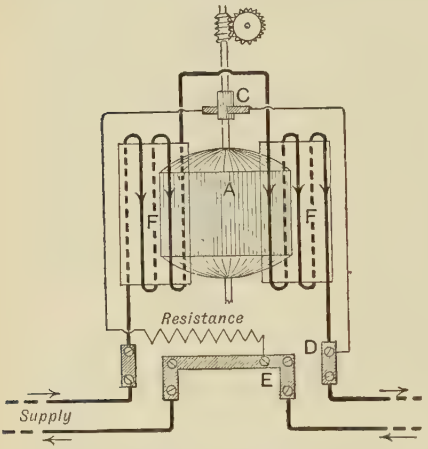


FIG. 265.—A METER FOR MEASURING ELECTRIC POWER.

UNDER THE INFLUENCE OF THE CURRENT IN THE COILS *FF*, THE ARMATURE *A* ROTATES, AND ITS RATE OF ROTATION DEPENDS UPON BOTH THE CURRENT AND THE VOLTAGE, HENCE THE WATTAGE IS INDICATED.

One or two examples will illustrate the usual consumption in lighting, cooking, etc. An electric lamp commonly used in

sitting rooms of average size is marked 200 V., 100 W., and this means that this lamp consumes exactly 100 watts in an hour when the mains are at a pressure of 200 volts. If the unit of supply is rated at 6d. for lighting, such a lamp can be used continuously ten hours for 6d. Another lamp used in smaller rooms is marked 200 V., 40 W., and this consumes only 40 watts per hour, and can be used continuously 25 hours for 6d. A so-called half-watt lamp consumes half a watt for each candle power obtained. Of course, lamps and other appliances should always be used in connection with the voltage indicated on them. An electric oven of average size consumes 3000 watts per hour, and if the rate for power consumption is 2d. the cost of this is 6d. per hour. Similarly, a small bowl electric fire consuming one unit will cost 2d. per hour.

Instruments used for measuring domestic and other consumption of electricity are known as **wattmeters** (Fig. 265), and these measure the product of volts multiplied by amperes, but many separate instruments—**voltmeters** (Fig. 266) for measuring electro-motive-force and **ammeters** for amperes—are commonly used in laboratories, engineering works, and for testing batteries used in connection with bell circuits, telephones, wireless sets, etc. There are many types of these instruments, some much more complicated than others, and we can consider here only those of more simple construction, such as the small pocket voltmeter one uses to test an accumulator or high tension wireless battery. Those most commonly employed are electro-magnetic in their mode of operation. The magnetic field of a wire carrying an electric current causes a movement or deflection of a small magnetised needle placed near the wire, or in many cases the coil itself is caused to move, and the extent of

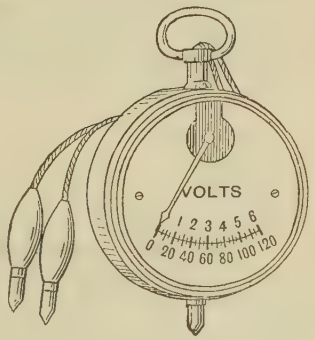


FIG. 266.—A POCKET VOLTMETER.

ONE OF THE TERMINALS ON THE LEFT IS USED FOR LOW VOLTAGES AND THE OTHER FOR HIGH VOLTAGES SUCH AS THAT OF A HIGH TENSION BATTERY USED WITH WIRELESS RECEIVERS.

this movement is related to the amount of current flowing along the wire.

If a wire is coiled around an ordinary compass needle the magnetic field of the current passed along it is balanced against the earth's magnetic field, which endeavours to keep the needle pointing magnetic north and south. Such an instrument, called a **tangent galvanometer,** works correctly only when it is previously placed in the right position with both the needle and the coil of wire in the magnetic meridian. Then the current strength has to be found by a calculation, and it is not read directly, so that it is better to use a different type of instrument in which the magnetic field of the current is not balanced against that of the earth.

Two magnetised needles of equal strength can be mounted together in such a way that the earth's field has no action upon the arrangement. The north pole of one needle is placed above the south pole of the other, and the two are firmly fixed together by a vertical bar. It is obvious that the action of the earth on one needle is counterbalanced by the action on the other, and such an arrangement is called an **astatic pair** (*i.e.* not standing), since it does not set itself pointing north and south as an ordinary compass does (Fig 267). If a coil of covered wire is placed around one of these needles, the magnetic field of a current passed along it can be balanced against a coiled spring or other device. Such a galvanometer can be placed in any position, and once it has been calibrated, or a scale of correct readings has been made, the current strength or voltage, as the case may be, can be read directly from a pointer which moves over the scale.

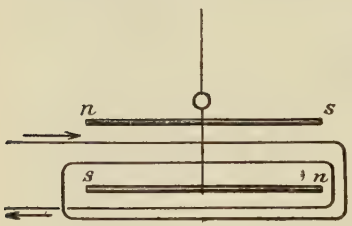


FIG. 267.—AN ASTATIC PAIR.

In an instrument designed for use as a voltmeter the coil consists of many turns of thin wire having a very high resistance, many hundreds of ohms, which is so arranged that it is always in parallel with the circuit being tested. In an ammeter designed

for measuring the amperes the instrument must not add any additional resistance, hence the coil consists of one turn of wide metallic strip and the full current of the circuit to be tested is indicated.

In some modern applications, such as X-ray work and wireless circuits, the currents are very small, a few milliamperes or thousandths of an ampere, and for measuring such currents a delicate and specially constructed instrument must be employed.

Wattmeters may be regarded as combined voltmeters and ammeters—in fact the wattage could be measured by means of a separate voltmeter and ammeter placed in the same circuit. The wattmeters used for measuring domestic and other consumption are self-recording, the total consumption being shown by figures representing units and tens, hundreds and thousands of units.

The insulation of electric lighting mains, and that of cookers and other apparatus, is tested by means of an **ohmmeter**, often termed a ' mega,' since it is capable of measuring resistances up to millions of ohms or **megohms**. In this instrument the current from a small hand-operated dynamo is passed along circuits arranged in such a way that any leakage in the mains or apparatus undergoing a test is indicated by a pointer and scale.

ELECTROMOTIVE FORCE THE RESULT OF WORK DONE

Mere quantity of electricity without pressure or voltage is of no use in practical life. In order to produce electricity at a potential high enough to do work, some sort of work must first be done. The potential of a voltaic cell is the result of chemical work done by the attraction of the zinc for part of the acid or other solution employed for that purpose. The more thorough this chemical work, the greater the resulting voltage, as shown by the better results obtained by cells having good means of anti-polarisation. In a dynamo the voltage depends upon the rate at which the magnetic field varies, and this of course depends upon the speed of the armature : more mechanical work must be done to rotate the armature quickly than is necessary for slower motion.

The power may be supplied by steam, petrol, coal gas, or falling water, but in all cases there is a definite relation between the amount of mechanical work done and electrical energy produced. A force that can lift 33,000 lb. weight through a distance of one foot in one minute is called one **horse power**, and this is equivalent to 746 watts, or 0·746 of the practical unit of electrical supply. As machines do not yield 100 per cent. of the energy employed to operate them, there is always some loss in changing mechanical force into electric power, also a certain amount of energy must be expended in overcoming the low resistance of the mains or conducting wires; consequently more than one horse power must be used at the power station to supply 746 watts for lighting or other purposes.

In connection with loss of energy and efficiency, it is better to use a high voltage and small current than a lower voltage and bigger current when transmitting electrical energy from a power station to some distant place. Two thousand watts could be transmitted as a current of 10 amperes at 200 volts, but it is better to transmit it as a current of say one ampere at 2000 volts. At the farther end where the electricity is to be consumed it must be re-transformed to 10 amperes at 200 volts. Generally, alternating current is employed.

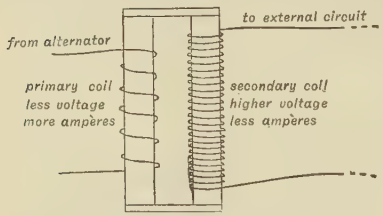


FIG. 268.—THE PRINCIPLE OF A STEP-UP TRANSFORMER.

These changes in voltage and amperage in alternating currents are brought about by means of apparatus called **transformers** (Fig. 268). A transformer is an induction or influence apparatus consisting of two separate coils of insulated wire wound on an iron core which strengthens the magnetic field of the arrangement. One coil is much longer and made of thinner wire than the other, and the relative length of the two coils determines the degree of current transformation. If the voltage is to be increased ten times, then the **secondary coil** must be ten times as long as the other **primary coil** through which the current from the generators is passed. If a current

of 10 amperes at a voltage of 200 is passed through the primary coil, then by electro-magnetic influence a current of one ampere at a voltage of 2000 is generated in the secondary coil. An apparatus of this kind which increases the voltage is called a *step-up* transformer. At the distant place of consumption a *step-down* transformer is employed, the current at 2000 volts being passed through a coil ten times as long as the secondary coil in which an induced current of 10 amperes at 200 volts is again obtained. The *secondary* coil of a transformer is always the one bearing the induced current.

CHAPTER XXXI

SOME RECENT DEVELOPMENTS OF ELECTRICITY

TRANSFORMERS are used for other purposes besides power transmission. An apparatus employed for the production of a higher voltage at the expense of current is a **low frequency transformer** used in many wireless receiving sets. Its mode of operation is similar to that of the larger apparatus used in power stations, and briefly described in the previous chapter. A shorter primary coil is placed against, but separated from, a longer secondary coil, the coil being wound around a soft iron core. In a transformer of good construction this core consists of a number of thin iron plates of laminae, since such an arrangement prevents the occurrence of *eddy currents* which would be formed in a larger continuous piece of iron. The function of the apparatus is to increase the voltage applied to the grid of a valve (see below) attached to the longer secondary coil, by passing the current from the plate of the preceding valve through the primary coil. The transformer is described as of low frequency because its work is concerned with the production of sounds in the loud speaker, and sound waves are of very much lower frequency than are the high frequency, electro-magnetic waves producing electric current in an aerial.

Another transformer of considerable practical value is known as an **induction coil** (Fig. 269).

As in other similar apparatus, there is a short primary coil composed of thick wire surrounded by a very much longer coil of thin wire. The wires are well insulated, and the coils are separated by waxed paper.

The primary coil is wound around a core consisting of a number of soft iron wires which prevent the formation of eddy

currents which would lessen the efficiency of the apparatus, just as local action does in the zinc of a voltaic cell (Chapter XXIX). Since currents are induced in the secondary coil only when a variation occurs in the magnetic field around the core, the battery current flowing along the primary coil is rapidly started and stopped by a make and break arrangement similar to that in an electric bell. An iron hammer is attracted to the magnetised core, and its movement causes a gap near the screw point so that the current is stopped, and the hammer springs back again. Every time the primary current is started an induced current occurs in the secondary coil in the opposite direction, and every

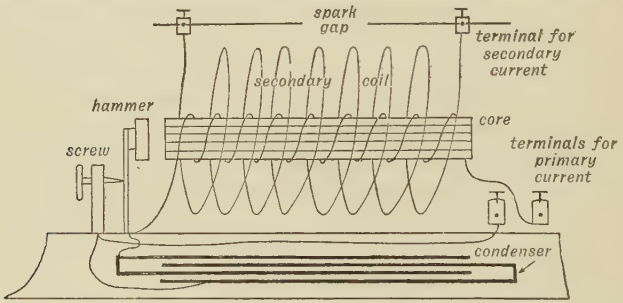


FIG. 269.—DIAGRAM OF THE PARTS OF AN INDUCTION COIL.

time the primary current is stopped an induced current in the secondary coil flows in the same direction as that in the primary.

A very important part of an induction coil is the condenser placed in the base of the instrument. This consists of one set of tinfoil plates alternating with the plates of a similar set, but separated from them by waxed paper. When the hammer is pulled away from the screw the primary current exhibits *inertia*, it does not stop absolutely at once, and is discharged into the condenser, and is then sent back into the primary coil when contact is made again.

By this means the efficiency of the apparatus is greatly improved. Small coils used for medical purposes are sufficiently powerful without a condenser. The voltage or E.M.F. of the secondary coil depends upon its length relative to that of the

primary coil. When the ratio is great, an E.M.F. of thousands of volts is produced, so that a spark discharge occurs across a gap between pieces of metal attached to the ends of the secondary coil. The insulation of the air particles in the spark gap breaks down, and the electric discharge zigzags or ramifies along the path of least resistance. A flash of lightning is a gigantic spark which is always forked or ramifying (Fig 285); so-called sheet or summer lightning being the reflection of a branching discharge taking place below the horizon. The length of spark obtained from an induction coil depends upon the size of the apparatus; the largest ever made was constructed by the electrical engineer Spottiswood, and gave a spark 42 inches long; but for X-rays and other purposes a coil producing a six-inch spark is quite large enough.

RÖNTGEN OR X-RAYS

During the latter half of the nineteenth century, many interesting discoveries were made by **Sir William Crookes** and others concerning the minute particles of which matter and electricity are composed. Whilst experimenting with electric spark discharges passed through rarefied gases contained in glass tubes, **Röntgen,** in 1895, discovered that certain radiations or wave-motions proceeding from these tubes possessed the power of penetrating sheets of paper and other objects which do not permit light rays to pass through them.

At ordinary atmospheric pressure, air and other gases are non-conductors of electricity, and it requires a very high voltage to break down the air resistance so that a spark or electric discharge passes. When the air is much rarefied and the pressure reduced to a very small fraction of its normal value, the electric discharge, consisting of a stream of minute particles of electricity or **electrons,** passes much more easily and the gas itself becomes luminous. Different gases show different characteristic colours; thus hydrogen appears red, carbon dioxide pale green, helium and argon bright red, neon, a deeper red, and so on. Tubes containing these gases very much rarefied are known as vacuum or discharge tubes; neon tubes in particular are used commercially for illuminated signs.

If the degree of exhaustion of the gas is increased further, the luminosity disappears, but the stream of electrons continues, and the glass itself becomes luminous. Since electrons are particles of so-called negative electricity, they are projected at a great speed from the cathode or negative wire of the tube, and for this reason the stream of electrons is known as the **cathode rays** (Fig. 376). If the stream of electrons strikes a target or piece of metal, the impact results in the production of electromagnetic waves of exceedingly short wave length ranging from 0·0004 to 0·8 of one millionth of an inch, too small to affect vision, but still capable of affecting a photographic plate. These extremely small waves are popularly known as **X-rays,** and are capable of penetrating many solid materials. Some substances are more transparent to these rays than others; thus the fleshy portions of the hand are more transparent than the bones, consequently the bones cast a deeper shadow than the flesh does in an X-ray photograph or radiograph.

FIG. 270.—X-RAY OF FOOT INSIDE A BOOT.
(By courtesy of Savoy Taylors' Guild.)

An X-ray tube (Fig. 271) is a globe having projecting parts carrying the electrodes, and containing air at a very high degree of rarefaction. The negative electrode or cathode is a curved piece of metal projecting the electrons so that they hit a target. The target itself is composed of tungsten and is called the **anticathode**. From this the X-rays proceed, though the glass

itself becomes luminous or fluorescent with a pale green light. Fluorescent substances are those which become luminous under the influence of X-rays, *barium platinocyanide* exhibiting this in a marked degree. If a piece of cardboard is covered with this substance a sensitive fluorescent screen is obtained. An object, such as the hand, placed in the path of the rays and in front of the screen casts a shadow, and as we have noted, the bones cast a deeper shadow than the flesh. A piece of steel embedded in the flesh casts a shadow deeper still.

A shadow picture is thus formed on the screen, but in surgical work a photograph is generally required. Of course a camera is not necessary, all that is required being a photographic plate wrapped in a paper light-proof covering. The part to be photographed is placed just above the plate and is exposed to the rays for a certain time, then the plate is developed in the usual way. With special apparatus dental surgeons can obtain radiographs of the teeth and gums, thus obtaining valuable information. X-rays are also employed by excise officials for the detection of contraband disguised in parcels, etc. Imitation diamonds can be detected by the fact that genuine diamond is opaque to the rays.

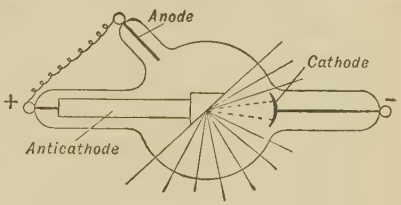


FIG. 271.—AN X-RAY TUBE.

WIRELESS TELEGRAPHY AND TELEPHONY

When an electric spark passes between the ends of a spark gap connected with an induction coil or other apparatus generating a high electromotive force, the discharge is not merely in one direction only; it surges forwards and backwards. In other words the discharge is *oscillatory* in character. Electric oscillations of this kind disturb the ether so that electromagnetic waves proceed in all directions away from the spark gap. The existence of such waves was suggested by **Clerk Maxwell** as early as 1864, and while admitting the great part played by **Marconi**, who made

wireless telegraphy a practical working affair, we must not forget the pioneer work of others who laid the foundations upon which this marvellous modern achievement rests. Nor must we overlook the fact that the reproduction of music in our homes, and the ability to carry on a conversation with persons on the other side of the world without wires is due to the genius of **Dr. J. A. Fleming,** who invented the **thermionic valve,** and to the American, **Dr. Lee de Forest,** who improved it.

Sir Oliver Lodge showed that when an oscillatory discharge or spark passed across a space or air gap in one circuit, another spark jumped across another gap in a separate circuit, placed at a little distance from the first, provided that the second circuit were properly ' in tune ' with the first. The original spark caused a disturbance in the separating medium or ether, and in virtue of this disturbance, electricity was generated by induction in the tuned circuit. Later he discovered means of producing similar effects when a distance of nearly 200 feet separated the two circuits. The famous German scientist, **Hertz,** in 1888, showed that the disturbance occurring in the intervening medium was of the nature of wave motion traversing the ether, consequently these electromagnetic waves are often termed **Hertzian waves.** Marconi discovered means of transmitting and receiving these waves over long distances. He found that by connecting his oscillatory circuit to the earth and by using elevated aerials the waves could be sent more effectively into space. In many of his earlier experiments performed at his home in Pontecchio he employed large pieces of sheet metal as aerials. In 1899 he succeeded in effecting wireless communication between England and France, and the first wireless messages passed between England and America in 1902. Quite recently Marconi has developed the **beam system** of wireless, in which the waves are projected by suitable ' reflectors ' as beams analogous to the beams of light projected by a searchlight. The beam system means less loss of energy and consequently greater carrying power.

Let us consider quite simply and without unnecessary detail how Hertzian waves are sent out and received.

A simple transmitter for sending out discontinuous waves or

spark signals, by which wireless telegraphy by Morse code is possible, consists of an induction coil and a spark gap, to which is attached a tuned aerial (Fig. 272). The tuning device which determines the length of the waves radiated consists of a condenser and an inductance coil, the lower end of which is connected with the earth. A tap key controlling the current flowing along the primary of the induction coil is worked by

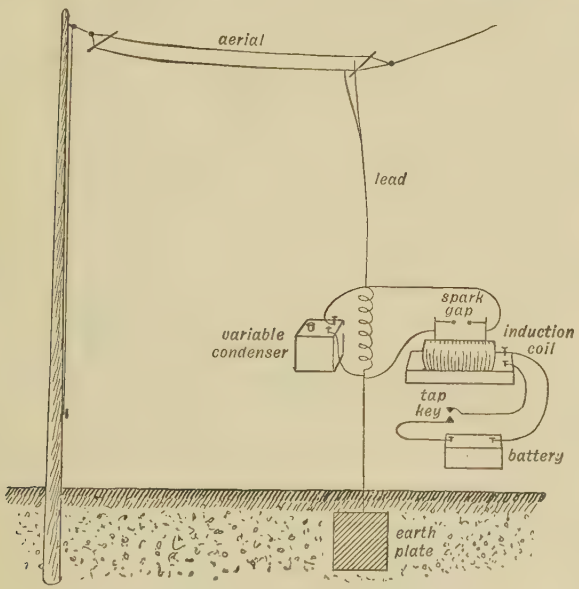


FIG. 272.—A SIMPLE CIRCUIT FOR THE WIRELESS TRANSMISSION OF 'SPARK' SIGNALS.

the operator, who sends out the desired combinations of dots or quick sparks, and dashes or sparks of longer duration. How are the waves radiated by this transmitting apparatus received and converted to sounds in a telephone at any receiving station?

Now, the ether waves, when they impinge upon the tuned aerial of a receiving apparatus, induce electric currents in the aerial, and these currents are oscillating or alternating, they race forwards and backwards along the aerial sytem. Such alter-

nating currents will not work a telephone, hence some **rectifying device,** commonly known as a detector, is necessary to cause currents flowing in one direction only to pass through the telephones or loud speaker. Certain crystalline substances, such as the mineral galena (lead ore), and the artificial product called

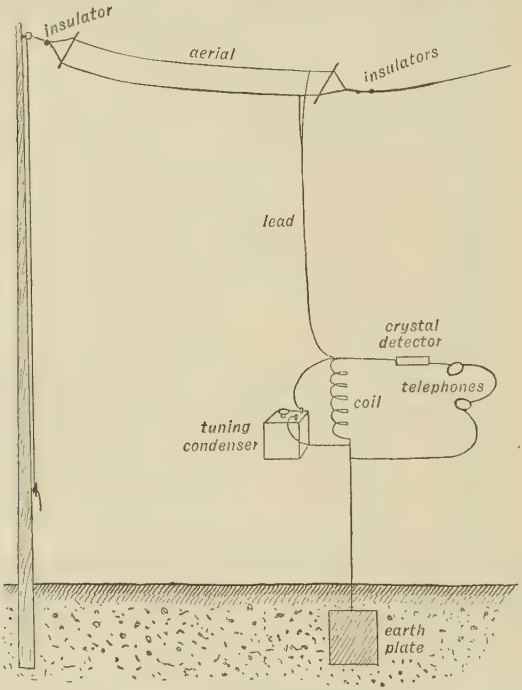


Fig. 273.—A Simple Circuit for receiving Wireless Messages, Music, etc.

carborundum, possess the property of allowing currents to pass in one direction only, hence we have crystal receivers, but their range of reception is very limited, merely a few miles ; even in the case of high powered stations, such as Rugby (commercial messages, etc.), or Daventry (broadcast programmes), clear reception by a crystal detector cannot be guaranteed at distances greater than 100 miles.

With any kind of receiving set the aerial must be tuned by means of a coil of wire and a condenser, so that it responds properly to the wave-length of the transmitting station.

The range of reception is greatly increased when rectification is performed by a thermionic valve. In order to understand how such a valve operates, we cannot do better than consider first the *two electrode* valve invented by Dr. Fleming in 1904 (Fig. 274). The two electrodes, or parts, consist of a metal **filament** which can be made white hot by a current from a low tension (*i.e.* at small voltage) battery or accumulator, and a cylinder of copper called the **anode** surrounding but not touching the filament. Both parts are enclosed in a glass bulb from which the air has been exhausted; thus the valve is a special kind of electric lamp. By means of wires passing through the glass the anode can be connected with the aerial system, and the filament can be connected to telephones which are also joined to the earth end of the aerial system. When the filament is rendered white hot by the battery current electrons escape from it. In valves of the **dull emitter** type, the filament is coated with thoria and the electrons are thrown off at a lower temperature.

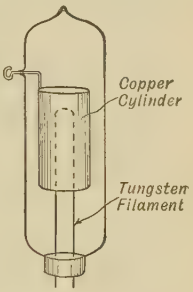


FIG. 274.—A FLEMING TWO-ELECTRODE VALVE.

The anode, being influenced by the alternating currents in the aerial, is at one fraction of a second positive, the next fraction of a second negative, and so on. When the anode is positive, electrons are attracted to it, and a current passes through the telephones, but when the anode is negative, it repels the electrons and no current passes through the telephones. Thus the lamp functions as a valve, permitting currents to pass through the telephones in one direction only, and sounds are possible. This simple receiving arrangement was employed in the early days of wireless transmission. Lee de Forest's three electrode valve is now used in receiving apparatus, though the two electrode valve still performs important work in transmitting stations where a high voltage current from an alternator is converted to a current in one direction. Similarly, such a valve is employed for the

rectification of alternating current for the purpose of charging accumulators as in trickle chargers and battery eliminators.

In the three electrode valve (Fig. 275) a third part, called the **grid**, consisting of a spiral of wire, is placed between the filament and the anode or plate. The anode, which is not connected to the aerial, is kept at a high positive potential by being placed in contact with the positive end of a high tension battery, usually having a voltage of 60 or more. Since the anode is always positive, there is a tendency for electrons to be drawn continually from the filament, but the grid acts as a policeman and regulates the traffic of electrons crossing to the plate. The grid is connected

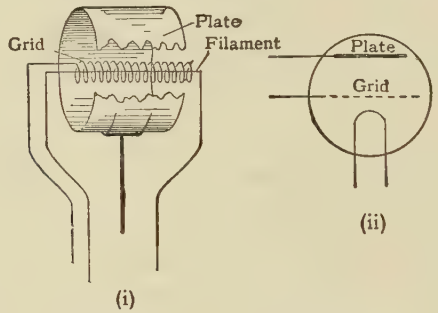


FIG. 275.—THE PARTS OF A THREE-ELECTRODE VALVE USED IN WIRELESS RECEIVERS.

(i) A COMMON ARRANGEMENT OF THE PARTS. (ii) A CONVENTIONAL DIAGRAM REPRESENTING A VALVE IN DIAGRAMS OF WIRELESS CIRCUITS.

to the aerial system and, as it were, receives its orders from the electric impulses surging up and down the aerial. At one moment, while the aerial current is in one direction, the grid is positive and helps in drawing electrons over to the plate, at the next moment, the aerial impulse being in the other direction, the grid becomes negative and prevents electrons from passing (Fig. 276). The grid is really part of the aerial system and partakes of all electrical fluctuations occurring in the aerial, with the result that exactly corresponding fluctuations occur in a one-direction current proceeding from the plate and operating the telephones, so that variations of sound take place. The telephones are connected to the plate of a three electrode valve.

In the case of wireless telephony, which reproduces continuous speech or music, discontinuous waves originating from sparks are of no use. **Continuous ether waves** are necessary, and these are now generally produced by three electrode valves, but sometimes the **arc system**, invented earlier by **Poulsen**, is employed at transmitting stations. The actual mode of producing continuous waves is of too technical a nature to be discussed here.

A wireless broadcasting station generates by electrical means a continuous wave motion of a definite wave length. For example, the waves radiating from the Oxford Street aerial of the London station are 361·4 metres long. For a few minutes preceding the commencement of a programme these **carrier waves** are proceeding through space, but are not subjected in any way to variations due to speech and music. Immediately the announcer speaks the wave form is modified, and these modifications are faithfully reproduced in the loud speaker at home. By what sequence of events is this result achieved? Stated very simply this sequence is as follows:

1. Sounds affect a **microphone** forming part of a circuit bearing electric currents. (2) These currents undergo variations according to variations of the sound influencing the microphone. (3) Such varying currents are superimposed upon the electrical impulses radiating the wireless waves. (4) The carrier waves are thus undergoing continual modification. (5) The currents induced by the carrier waves in a receiver's aerial are correspondingly modified. (6) The plate current of a receiving set undergoes an exactly equivalent series of modifications. (7) The telephones or loud speaker operated by this plate current reproduce sounds exactly similar to those made in front of the microphone at the transmitting station.

In spite of these numerous transformations of energy, the music reproduced is surprisingly free from distortion in a good wireless receiving set.

The actual volume of sound obtained from a loud speaker is considerable though the amount of electrical energy developed in the aerial is small, and the extra energy needed is supplied by batteries. In order to use this additional energy in the necessary way the three electrode thermionic valve is again employed, this

time as an **amplifier.** When a series of electrical impulses are given to the grid of a valve an exactly similar but stronger series of impulses proceed along the wires connected to the plate or anode, hence there is an amplification or magnification of the original impulses. If a valve is used to magnify the impulses of the aerial *before* they are rectified or detected, the valve is described as a high frequency amplifier, but if it is used to magnify the impulses *after* rectification the valve is known as a low frequency amplifier. The terms high and low refer to the

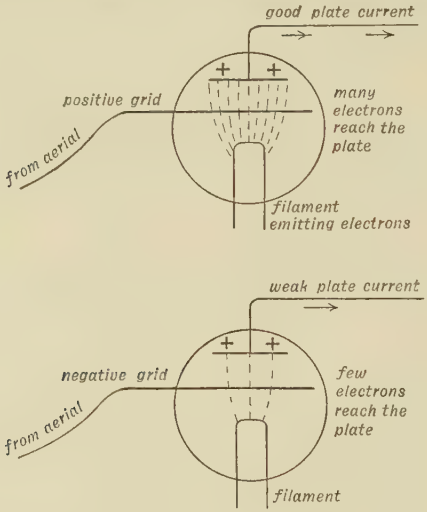


Fig. 276.—Explanation of the Action of a Three-electrode Valve as a Detector.

great difference in frequency between the aerial currents and the sounds issuing from a loud speaker, as explained at the commencement of this chapter. Space does not permit any description of the various modes of joining or ' coupling ' valves together ; for such information a student must refer to the various journals dealing adequately with the construction of wireless sets.

Wireless waves may also be used for **direction finding** either at sea or on land. A frame aerial or rectangular hoop of wire receives wireless impulses best, and consequently gives loudest

signals, when it is arranged in a direction end on (*i.e.* not broadside) to the direction in which the ether waves are travelling. Thus a ship is able to take its bearings in relation to the position of a land station sending out wireless waves.

Other developments which are in progress but as yet far from being complete are **telephotography** and **television.** In the former, pictures of events are sent by wireless and reproduced in the press, the time taken in the operation being only a few minutes. The aim of television is to enable people to see events happening at a distance, just as the telephone enables one to hear a voice or music at a distance. Though, however, it is possible now to broadcast from a central station the face of a performer so that it can be seen as a blurred image in suitable receiving apparatus, there is no immediate possibility of people being able to see one another while they speak.

CHAPTER XXXII

STATIC ELECTRICITY

As early as 600 B.C. it was known that a piece of amber rubbed by wool possessed the power of attracting small fragments of straw, etc., and the word electricity is derived from **electron,** the Greek word meaning amber. A piece of amber excited in this way is said to be electrified, the electricity developed making itself apparent by its power of attraction over small bodies. Sealing-wax rubbed by flannel, glass rubbed by silk, cat's skin stroked by a dry hand, and many other substances, exhibit similar properties. It must be noted that both the substance rubbed and the rubbing material are electrified, though it is not always easy to demonstrate this fact. When you stroke a cat's back in dry frosty weather small sparks are visible, a crackling sound may be heard, and the cat's hairs stand up straight, because any hair endeavours to get away from others near it. Your hand is also electrified, but the electricity produced on it immediately escapes to the earth through your body. If you were to stand upon a slab of thick dry glass, however, your hand would exhibit the power of attraction over light bodies, pieces of paper for example, because the glass is an insulator preventing the escape of electricity to the earth. The cat's fur itself is an insulator, hence its electrification becomes apparent. Your body, pieces of metal, and water are all conductors which permit electricity to escape. Because moisture is a conductor, experiments connected with this kind of electricity can be performed only when the apparatus employed is quite dry.

The electricity produced on glass rubbed by silk does not behave in exactly the same way as the electricity produced on sealing-wax rubbed by flannel. About 200 years ago it was

believed that there were two distinct kinds of electricity, and **Benjamin Franklin,** whose kite experiments demonstrated that lightning is a form of electric discharge, proposed the terms **positive** and **negative** for the two kinds. We still use these terms, though modern researches have considerably modified our views about the nature of electricity. It is quite easy to show that electricity behaves as if there were two distinct kinds. If a small piece of dried elder pith is suitably suspended by a piece of silk thread, we have a very simple kind of **electroscope** (Fig. 277).

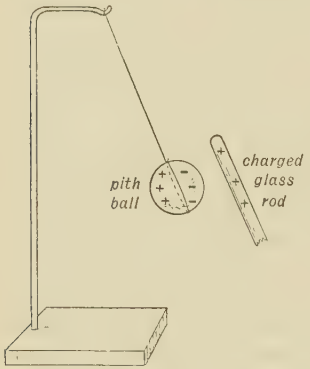


FIG. 277.—THE PITH BALL ELECTROSCOPE.

Now, if glass rubbed by silk is brought near, but not allowed to touch, the pith ball, the latter is attracted towards the glass. If the ball is now made to touch the glass, it receives a small charge of the electricity and is repelled or pushed away.

Electric charges of the same kind repel each other, and this is similar to the repulsion between magnetic poles of the same kind. The pith ball now holds a small charge of so-called positive electricity, and if a piece of sealing-wax rubbed by flannel is brought near the pith ball, the latter is attracted by the electricity on the wax. The electricity on glass repels the charged ball, that on wax attracts it; from these facts we infer that the electricity on the wax is of the other kind, and we call it negative.

Evidently a *positive charge exerts a mutual force of attraction with a negative charge.*

The positive electricity on the pith ball may be discharged to earth by momentary contact with the hand, and then the ball can receive a charge of negative electricity by contact with the excited sealing-wax. As soon as it receives this negative charge it is repelled by the wax, thus verifying the rule that like charges, whether both positive or both negative, exert a force of repulsion. Once a pith ball or other form of electroscope is given a known

charge of electricity, it can be used to determine the sort of electricity on any electrically exerted substance.

An interesting case is afforded by two pieces of glass of similar composition, but one rubbed with cat's skin, the other with silk. It will be found that the first piece of glass will be electrified negatively, the second piece positively, thus showing that the nature of the rubbing material is a factor in the case.

Electricity of this nature was formerly called **frictional**, because of the rubbing process, but in reality contact of dissimilar substances is the essential condition, the friction merely ensuring a good contact. Since electricity produced in the way we have just considered does not flow as a current but remains *standing* on the charged material, a very suitable name is **static** electricity, and this term is now generally employed.

ATOMS AND ELECTRONS

Since electricity is rapidly transferred from one body to another in contact with it, and since it flows along wires at a great speed, it was for a long time believed to be in the nature of a fluid, but recent investigation on the nature of the atoms composing various substances have shown that it consists of minute particles called **electrons**, or more correctly, the so-called *negative* electricity consists of electrons.

(i) The Hydrogen Atom **(ii) The Helium Atom**

FIG. 278.—ATOMIC STRUCTURES.
PROTONS SHADED, ELECTRONS UNSHADED.

It was formerly believed that an atom was the smallest conceivable particle of matter and could not be composed of still smaller units. But we have now good reasons for believing that any atom is not a simple indivisible structure, but is composed of a nucleus consisting of one or more **protons** and electrons surrounded by a space in which one or more electrons or particles of negative electricity revolve at great speed (Fig. 278). An atom is

thus like an exceedingly small solar system, the nucleus to some extent corresponding to the sun, and the revolving electrons corresponding to the planets. The simplest atom is that of hydrogen and consists of a single proton forming the nucleus around which a single electron is revolving. Other forms of matter consist of atoms more complicated than this, there being in some cases quite a large number of revolving electrons as well as some electrons helping the protons to build a complicated nucleus.

A more detailed account of atomic structure is given in a later chapter dealing with radium and radioactivity, but it must be observed here that in the process called electrification some of the electrons are torn away from atoms so that the remainder, being deficient in negative electricity, appears to be charged positively, and in its endeavour to capture electrons it exerts an attracting force for negative electricity. The escaped electrons give a charge of so-called negative electricity to the body to which they become attached.

Thus when sealing-wax is rubbed with flannel, electrons are torn off the atoms in the flannel (which appears positively charged) and give a negative electrification to the wax. According to this view, a current of electricity consists of an extremely rapid motion of free electrons along a wire or other conductor.

ELECTROSTATIC INDUCTION

A redistribution of electrons can be accomplished by influence without contact. Just as a piece of steel or iron can be magnetised by induction (see Chapter XXVII), so an insulated body can be electrified by electrostatic induction. The pith ball of the simple electroscope is attracted towards the electrically charged glass rod because electrons are attracted to the side of the ball facing the glass. In the same way a large metal ball insulated by a glass support can be influenced by a charge of electricity placed near, but not in contact with it (Fig. 279). If the inducing charge is of the so-called positive kind, then the electrons are attracted to the side of the ball facing the charge and the further side of the ball is deficient in electrons. Now if *any* part

of the ball is momentarily touched, or earthed, while the inducing charge still exerts its influence, additional electrons are drawn from the earth, which acts as an inexhaustible reservoir. If the connection to earth is just removed, and then the inducing charge is taken away, the ball is left with an excess of electrons and is said to possess a negative charge of electricity. The metal ball is thus charged by induction, and the inducing charge is not in any way reduced quantitatively. Should the inducing charge be of the negative kind, then electrons are repelled to the further side of the ball and will escape to earth when the ball is momentarily touched while the inducing charge is still present, and on the removal of this influence, the ball will be deficient in electrons, or possesses a so-called positive charge.

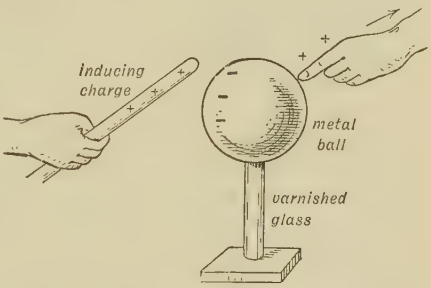


FIG. 279.—CHARGING A CONDUCTOR BY MEANS OF ELECTROSTATIC INDUCTION.

One or two facts concerning this mode of electrification must be observed. Any number of insulated bodies can be charged by the influence of a single inducing charge, the work done in bringing the charging body near the various objects, one at a time, providing the energy needed. Each time, the total induced charge is equal to the inducing charge, though it is difficult to obtain all of the induced electricity upon one object, since the influence is exerted in the electric field which extends in all directions around the inducing charge.

The nearest approach to obtaining all the induced electricity on one body occurs when a charged ball is lowered by a silk thread into a tall insulated metal can with a narrow mouth.

The nature of the non-conducting medium separating the inducing charge from the object under influence is a very important factor of induction. Dry air is taken as the standard medium, and it is found that other media, such as rubber, glass, mica, and porcelain exhibit various capacities for transmitting

induction force. Hence we have specific inductive capacity, that of air being 1, that of flint glass 7·4, and so on. In all cases the intervening medium is strained by the inducing charge, and it is largely by reason of this strain that induction takes place. When a spark occurs, the medium (usually air) breaks down, but heals itself, as it were, after the discharge has taken place.

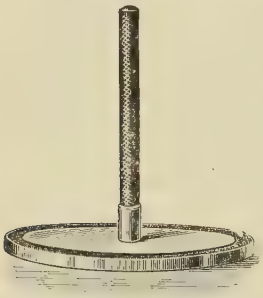


Fig. 280.—An Electrophorus.

A simple piece of apparatus employed for obtaining charges of electricity by induction is the **electrophorus** (Fig. 280). This consists of a circular plate of vulcanite, which is electrified by being rubbed with cat's skin. Negative electricity generated on the surface of the plate acts inductively upon a circular metallic disc placed upon it, and held by means of an insulating glass handle. The metallic disc does not become charged by contact, except perhaps at a few points, because a thin layer of air separates most of it from the vulcanite plate below.

Electrons are repelled to the top surface of the metal, and on touching it momentarily with the finger they escape to earth. Then upon lifting the metallic plate it is charged positively, since

Fig. 281.—The mode of working of the Electrophorus.

there is a deficiency of electrons. The operation can be repeated several times and the electric charges given to other bodies by contact. The electrophorus is more suitable for demonstration purposes than for anything of a more practical nature.

A larger and more useful induction apparatus capable of giving considerable charges of electricity is the **Wimshurst machine,** which is sometimes employed for the generation of X-rays when

an induction coil is not available (Fig. 282). Two varnished circular glass plates each carry a large number of metallic sectors placed radially. As the two plates are caused to rotate in opposite directions these sectors come in contact with metallic brushes placed at certain positions. Though these brushes in the first case give by friction a small initial charge to the sectors, their main function is to touch any sector at the moment it is opposite an inducing charge on a sector on the other plate. Thus the brushes act in the same way as a finger which touches the metallic disc of the electrophorus. At two other positions the charged sectors come in front of metallic combs or sets of points placed horizontally. Now, an electric charge escapes from points, consequently electricity proceeds from the points to the sectors producing electric equilibrium there, but leaving an excess of electricity on the metallic objects attached to the combs.

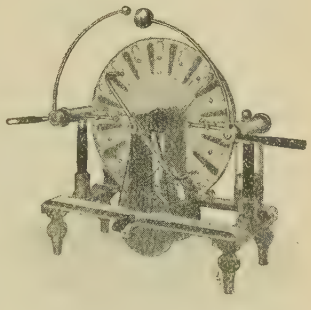


FIG. 282.—A WIMSHURST MACHINE.

These collecting objects which store the electricity until a spark discharge occurs are known as **Leyden jars**, from the fact that they were first used at Leyden in Holland.

FIG. 283. A LEYDEN JAR.

CONDENSERS

A Leyden jar (Fig. 283) is a good example of a **condenser** and is composed of glass well varnished with shellac and partly covered both outside and inside with coatings of tinfoil. The inner coating is in contact with a piece of chain attached to a brass rod terminating in a knob touching the metallic frame supporting the combs of the Wimshurst machine. Thus by contact the inner coating is charged with electricity, and the quantity it can hold depends largely upon the size of the Leyden

jar. But the capacity of the condenser is determined by another factor in addition to size. The outer coating of the jar is connected with the earth, so that electricity obtained from the earth exerts an attracting influence upon the inner coating, which is thus enabled to hold more electricity than it would do otherwise.

Any condenser consists of two separated plates, or sets of plates, one being connected to earth or other body functioning as a reservoir of electricity. In wireless circuits condensers play a very important part, both those having a fixed or invariable capacity and others in which the capacity can be varied by means of a set of movable plates which are interleaved with and move between a set of fixed plates.

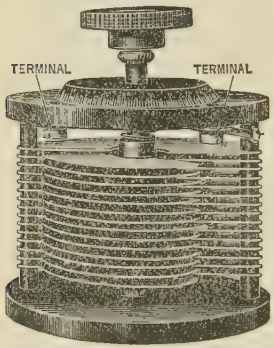


FIG. 284.—A VARIABLE CONDENSER.

So far as tuning a wireless aerial to a given wave-length is concerned, an increase of capacity obtained by a variable condenser (Fig. 284) is equivalent to the use of a larger inductance coil. It is very inconvenient to make slight alterations in the length of a coil, hence a coil of suitable length is used in conjunction with a variable condenser. Most wireless receiving sets contain several small fixed condensers which function in rather a different way. The ordinary one-way current from the low tension battery cannot pass through such a condenser, but high frequency oscillating impulses can pass by means of influence. Variations in the electrical condition of one plate produce similar variations in the other plate though a non-conducting substance, usually mica, separates them. For this reason such a fixed condenser is often described as a by-pass for oscillating high frequency currents.

THUNDERSTORMS

Large quantities of static electricity collect in clouds owing to disturbances of the atmosphere, particularly the rapid move-

ment of air columns due to sudden changes in temperature. Suppose that a large cloud becomes charged negatively, then it exerts a powerful inductive influence upon other clouds and upon the surface of the ground below. Electrons are repelled,

(*Photo. Dr. W. J. S. Lockyer.*)

FIG. 285.—LIGHTNING.

THE ELECTRIC DISCHARGE RAMIFIES IN TAKING THE PATH OF LEAST RESISTANCE.

so that the other clouds and ground become charged positively. Objects on the ground also share in this electrification, and though discharge commonly occurs between clouds, it sometimes happens that a flash of lightning or large spark passes between a tall object, say a tree, and a charged cloud. When this

discharge happens, the ground and objects regain electrical equilibrium instantly, and it is this sudden alteration in electrical condition that is dangerous to people or cattle situated near the tree. The change takes place so suddenly that fatal results often occur, and since the disaster is due to the return of normal conditions, the phenomenon is known as return shock. The highest objects reach nearest the clouds and are naturally the most likely to be struck, hence the safest places during a thunderstorm are those near the ground and away from trees, etc. Also, water in ponds and ditches should be avoided.

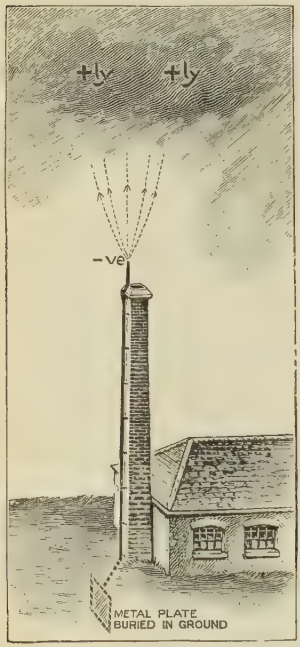


FIG. 286.

A LIGHTNING CONDUCTOR DISCHARGES ELECTRICITY OF THE OPPOSITE KIND TO THAT IN A CLOUD, THUS TENDING TO NEUTRALISE IT.

Since an electric charge always gets as near to the inductive influence (the cloud) as possible, a particularly safe place is any dry hollow in the ground where there are no trees. If it were not for the fact that a building may be struck and persons injured by falling masonry, etc., the inside of a house would be a perfectly safe place. Faraday demonstrated by placing himself with delicate electroscopes inside a large metallic box, which was then strongly electrified, that when the disturbing influence is outside, electrical charges always collect on the outside of a body. Neither he nor his instruments experienced the slightest electrical disturbance when within the charged chamber.

Electricity accumulates near points, so that the charge becomes too great to remain and there is a leakage. The air particles near the points become charged, are repelled, more particles take their places and the process is continued. In this way there is a

stream of electricity escaping, a fact which explains the use of a lightning conductor, which consists of several pointed metallic spikes connected by a thick metal band with the earth (Fig. 286). The conductors are placed on high chimneys, churches, etc., and in discharging electricity of the opposite kind to that in a cloud, they tend to neutralise it and so often prevent lightning from taking place. When a thunderstorm occurs in spite of lightning conductors it is because the latter are not numerous enough to cope with the situation, and discharges frequently occur between clouds too high to be influenced by conductors.

Air normally offers a very great resistance to the passage of electricity, consequently it requires an enormous difference of potential, probably millions of volts, to cause a flash of lightning. As in the case of smaller spark discharges obtained from a Wimshurst machine or an induction coil, the discharge is oscillating and zigzags about in taking the path of least resistance.

QUESTIONS AND EXERCISES

[*Questions marked* C.S.C. *are taken from papers set at Civil Service Commission Examinations, with the permission of the Controller of H.M. Stationery Office* ; *and those marked* O. and C. *are from Examinations of the Oxford and Cambridge Schools Examination Board.*]

PART II.

MECHANICS, HYDROSTATICS, ETC.

1. When a body is weighed on an ordinary balance at different points on the earth's surface its weight appears to remain constant, but if a spring balance be used the weight varies from place to place. Explain this. [O. and C.]

2. Explain the formation of marine tides.

3. Describe some mechanism employed for using the energy of falling water.

4. How is the period of swing of a pendulum related to its weight, its length, and the amplitude of the swing ?

5. What is meant by acceleration due to gravity ? Mention some practical consequences of such acceleration.

6. Explain why a man leans forward when climbing a steep hill.

7. How would you determine the centre of gravity of an iron hoop made by joining together two semicircles, one thicker than the other ?

8. What is the meaning of the terms velocity, mass, force, work, energy, inertia ?

9. What is meant by the *velocity ratio*, *mechanical advantage*, and *efficiency* of a machine. [O. and C.]

10. Explain the action of a ' Jack ' in lifting the wheel of a motor-car. [O. and C.]

11. Explain the principle of a lever, and describe the action of (*a*) a pair of scissors, (*b*) old fashioned coal tongs, (*c*) nut crackers.

12. What is meant by momentum ? Describe appliances which make use of momentum.

13. Describe some form of pulley employed by a builder or engineer.

14. Explain carefully the distinction between *mass* and *weight*. Two children whose weights are respectively 56 and 70 lb. are playing

on a see-saw. If the lighter child is 5 feet from the balancing point where should the other be placed ? [O. and C.]

15. A man can pump 25 gallons of water per minute to a height of 16 feet. How many foot-pounds of work does he do in an hour ?

16. What is the difference between kinetic energy and potential energy ?

17. Define work, and describe an experiment to prove that a falling ball is capable of doing work.

18. What is the mechanical advantage of a lever the load arm of which is 30 cm. long and the effort arm 135 cm. long ?

19. Give in a few words the principle of the screw.

20. When a glass capillary tube is put into water it is found that the water stands at a higher level in the tube than it does in the containing vessel. Discuss this, and describe some other phenomena which are due to the same cause. [O. and C.]

21. Explain why salt or sugar dissolves in water.

22. What is meant by *diffusion* ? Mention some practical consequences of diffusion in liquids and gases.

23. A piece of steel is highly elastic, but a piece of rubber is not so elastic. Explain these statements.

24. What property in particular is possessed by liquids and not by solids ? And what character has a gas which neither liquids nor solids possess ?

25. Explain the nature of the forces which mould a drop of water hanging from a glass rod.

26. Explain why a ship made of iron will float in water though iron itself is heavier, bulk for bulk, than water.

27. 1 c.c. of lead (sp. gr., 11·4) and 21 c.c. of wood (sp. gr., 0·5) are fixed together. Show whether they will float or sink in water.

28. What is the Plimsoll line ? Explain the value of this line in navigation.

29. State the principle of Archimedes, and show how it applies to a solid floating in a liquid. [C.S.C.]

30. What instrument is employed to determine the specific gravity of acid in an accumulator, and how does it operate ?

31. Explain the principle of the hydraulic press.

32. How would you determine the specific gravity of a piece of iron ?

33. State Boyle's Law, and describe some form of apparatus employed to verify the law.

34. Describe a Fortin's barometer, and explain how it measures the pressure of the air.

35. Make a sketch showing how a common pump works. Often when a pump fails to draw, a bucketful of water poured into it will start it working ; how do you explain this ? [C.S.C.]

36. How is the pressure of the atmosphere measured? What difference would you expect to find between the pressure at the foot of a mountain and that at its summit? [O. and C.]

37. 'An anti-cyclone is stationary over the British Isles.' Explain this statement, and describe the weather experienced at the time.

38. Describe some mechanism in which ordinary atmospheric pressure is used to operate it.

39. What is a siphon? Explain its action.

40. Describe the action of the vacuum brake used on railway carriages.

HEAT.

1. When most bodies are heated they expand. Give examples in which this expansion is (*a*) utilized, (*b*) counteracted. [O. and C.]

2. Explain the construction and mode of working of a mercurial thermometer.

3. Explain as fully as you can what is meant by (*a*) the temperature of a body and (*b*) the quantity of heat it contains. How many calories will be given out by a block of copper weighing 140 grams in cooling from 99° C. to 14° C. (Specific heat of copper = 0·1.) [O. and C.]

4. Define each of the following: British Thermal Unit, calorie, large calorie.

5. Why are thermometer tubes usually of very fine bore, and why are they provided with bulbs?

6. Convert the following into temperatures on the Centigrade scale: 71° F., 0° F., −40° F.

7. What is meant by the coefficient of linear expansion? If the coefficient of linear expansion of copper is 0·0000168 find the length of a copper rod at 200° C. if it measures 2 metres at 0° C.

8. 15 litres of air measured at 27° C. are cooled to 7° C. By how much will the volume diminish?

9. The pendulum of a clock varies slightly in length with changes of temperature. Describe devices by which such changes in length may be counteracted.

10. What is Charles's Law? Explain how the pressure of a gas conforms to this law when the volume is constant.

11. Outline briefly the transformations of energy which occur when a steam engine is being driven by a coal-fired boiler. [O. and C.]

12. Give some account of the action of a motor car engine. [O. and C.]

13. Heat is now regarded as a form of energy. What evidence led to this view? Give a brief account of any one of Joule's experiments that helped to establish the relation between the foot-pound and the thermal unit. [C.S.C.]

14. Explain the action of the Diesel oil engine.

15. Give a description of the steam turbine invented by Sir Charles Parsons.

16. What is meant by the 'Otto cycle'? Describe an engine operated by the explosion of a mixture of coal gas and air.

17. Give a brief account of the history of the steam engine.

18. Give an account of a circulating hot water system as used in a small house. [C.S.C.]

19. What is meant by 'ventilation,' and how is it obtained in (*a*) an ordinary living-room, (*b*) a coal mine. [C.S.C.]

20. By what different means may heat be transferred from one body to another? Give examples of each method. [O. and C.]

21. Describe the influence of clothing on bodily temperature.

22. Give an account of the permanent winds of the world, their cause and distribution.

23. Explain the action of an ordinary vacuum flask.

24. What is meant by 'latent heat'? How much ice will melt in 100 grams of water initially at 16° C.?

25. Explain the formation of dew, frost, clouds, and fog.

26. Describe the use of liquid ammonia for purposes of refrigeration. The latent heat of vaporization of ammonia is 340 calories per gram. Explain what this means. How many grams of ice at 0° C. can be made from water at 12° C. by the vaporization of 200 grams of liquid ammonia? The latent heat of fusion of ice is 80 calories per gram. [C.S.C.]

27. The rate at which wet clothes become dry when they are hung up in air depends both upon the condition of the air and upon the nature of the material. Explain this statement. [C.S.C.]

28. Describe the effects produced by heating (*a*) a gas, (*b*) a liquid, (*c*) a solid. [O. and C.]

29. Why does a muddy road dry better on a windy and warm day than on a quiet and damp day?

30. Describe a simple form of hygrometer, and explain what measurement is made with it.

LIGHT.

1. Describe a simple experiment devised to show that light travels in straight lines.

2. What is meant by 'umbra' and 'penumbra'? Illustrate your answer by means of sketches.

3. How do you account for the blue colour of the sky and the green colour of a leaf? [C.S.C.]

4. Describe the method you would use to produce a spectrum by means of a prism. How is a rainbow produced in the sky? [O. and C.]

5. Explain what is meant by wave motion, and illustrate your answer by reference to the transmission of light and sound. [O. and C.]

6. Why is it difficult to match coloured fabrics accurately by artificial light ?

7. Explain how the brilliant colours seen in the sky during a vivid sunset are produced.

8. Describe some form of photometer, and explain how you would use it to compare the candle power of two sources of light.

9. Explain the law of inverse squares in connection with the intensity of light.

10. How do different decorative colour schemes for rooms influence the illumination obtained in such rooms ?

11. What is a foot-candle ? Explain the principle of a light meter.

12. Distinguish between glare and diffused light.

13. Describe briefly the different kinds of light installations suitable for country houses beyond the reach of gas and electricity.

14. Explain clearly how it is that an image is produced by reflection at a plane mirror. How is it that the image of the surrounding objects formed by reflection at the surface of a lake appear upside down ? [C.S.C.]

15. The driver of a motor car is supplied with a convex mirror in order that he may see the roadway behind him. Explain how it is that he is able to do this.

16. Describe a simple periscope employed for obtaining a view of the country on the other side of a wall or trench.

17. Explain carefully why all objects used as mirrors have very smooth surfaces.

18. Calculate the distance and size of the image of an object placed 12 cm. in front of a concave mirror of focal length 9 cm.

19. Draw diagrams to illustrate the formation, in a concave mirror, of (*a*) a real image, (*b*) a virtual image. Explain the structure of a motor head lamp. [O. and C.]

20. Draw a diagram to illustrate the passage of light through a simple astronomical telescope. What addition must be made to such a telescope for terrestrial uses ? [O. and C.]

21. What kind of lens would you use for a magnifying glass ? Draw a diagram to explain its action. On what does its magnifying power depend ? [O. and C.]

22. Describe the construction and mode of action of the human eye. To what is short sight due ? [O. and C.]

23. Draw diagrams to show the apparent position of a point on the bottom of a river (*a*) when one is looking straight down upon it, (*b*) when one is looking at it from a distance. [C.S.C.]

24. An object is placed 20 cm. from a convex lens and an inverted image is formed 4 times as large as the object. Find the focal length of the lens.

SOUND.

1. How is sound propagated? Is the velocity of sound in air constant?

2. What is a hydrophone, and for what purpose is it used?

3. Explain what is meant by longitudinal wave motion.

4. What is the difference between a musical note and a noise?

5. Give some account of the different ways in which a musical note can be produced, and explain how its pitch can be varied. [O. and C.]

6. Explain the formation of echoes. In what ways may an echo be useful?

7. How is the difference between the pitch, loudness, and quality of two sounds accounted for? [C.S.C.]

8. How can the frequency of a tuning fork be determined?

9. What is meant by resonance? Describe some musical instruments the action of which depends upon resonance.

10. What is a sonometer, and for what purposes is it used?

11. How is sound produced by the human voice and received by the ear?

12. Explain carefully each of the following: fundamental, harmonic, octave.

13. Describe the different schemes of pitch employed in connection with instrumental music.

14. Explain the action of (*a*) an ordinary organ pipe, (*b*) a reed organ pipe.

MAGNETISM AND ELECTRICITY.

1. If you were given a steel bar, how would you discover whether it was magnetised and which was the N. pole? How would you magnetise it if it were not already a magnet? [O. and C.]

2. Explain the action of the magnetic compass. Why should one be careful to see that there is no iron in the neighbourhood of the compass when taking a reading? [O. and C.]

3. Write down what you know of terrestrial magnetism.

4. Describe with diagrams the working of an electric bell. Why are bells usually worked by a battery and not by the current used for electric light? [C.S.C.]

5. Explain the principle of a simple form of dynamo, and show how a continuous current may be obtained from it. [C.S.C.]

6. Describe the construction and mode of working of a Bell telephone.

7. What is an alternator, and how may currents be passed from an alternator to an external circuit?

8. Give an account of the different effects which may be observed

when an electric current is passed (*a*) through a thin copper wire, (*b*) through a solution of copper sulphate between copper electrodes. [O. and C.]

9. When an electric current flows in a suitable circuit it produces heat, magnetic, and chemical effects. Describe experiments by which you would demonstrate the production of these effects. [O. and C.]

10. Describe the construction and mode of working of an arc lamp.

11. State the laws of electrolysis, and give particulars of any electrolytic method for measuring current.
Describe the process by which articles are silver-plated. [C.S.C.]

12. For what purposes other than lighting is an electric arc lamp used ?

13. In what ways is electrolysis useful besides electro-plating ?

14. Write a short account of two forms of battery which may be used for the production of an electric current. [O. and C.]

15. Outline the changes that take place in the charging and discharging of an accumulator, and explain why ' pasted ' plates are now commonly employed. What advantages and disadvantages does the accumulator possess as compared with the dry cell ? [C.S.C.]

16. What is meant by ' local action ' and by ' polarisation ' ? How are these defects remedied ?

17. Give some account of the pioneer work done by Galvani and Volta.

18. Explain the meaning of the statement that the electric current flows in a circuit.

19. Explain the cause of *Polarisation*, and describe the chief method of preventing it.

20. Describe the parts and mode of working of an accumulator having lead plates.

21. Explain the meaning of the terms voltage, resistance, and current. How are the properties for which these names stand related to one another ?

22. Electric circuits may be connected (*a*) in parallel, (*b*) in series. Explain this. Two similar electric bulbs whose resistances are each 300 ohms are connected (*a*) in parallel, (*b*) in series across 100 volt mains. What will be the current in each case ? [O. and C.]

23. What is the Board of Trade unit of electric power, and how are such units measured in connection with home consumption of electricity ?

24. Explain the construction and mode of working of a simple voltmeter.

25. A certain electric lamp is marked ' 100 watts, 220 volts.' Explain the significance of these terms. Calculate (*a*) the current taken by the lamp, and (*b*) the resistance of its filament. [C.S.C.]

26. If a 16 C.P. 100-volt lamp consumes 35 watts, what is its resistance and what current does it take ?

27. Explain carefully what is meant by electromotive force. What determines the E.M.F. of a battery, and of a dynamo ?

28. Explain the terms volt, watt, Board of Trade unit. A lamp is marked '50 watts'; explain this. What other information would you require to ascertain the current the lamp would take ? [C.S.C.]

29. Explain the principle of a low frequency transformer. In what ways are transformers of importance in the transmission of electric power ?

30. Explain the mode of generation of X-rays, and the way in which a radiograph is taken.

31. State the general principles in transmitting and receiving wireless waves, and describe in detail any form of crystal *or* valve detector. Explain why it is required at all. [C.S.C.]

32. Say what you know of the work of Sir Oliver Lodge, Marconi, Fleming, and Hertz in connection with wireless telegraphy and telephony.

33. In what way is the three-electrode valve an improvement on the earlier two-electrode valve ?

34. Explain the processes of charging an insulated metal ball (*a*) by conduction, (*b*) by induction. Illustrate your answer by diagrams. [O. and C.]

35. How can you tell whether the electric charge on a body is positive or negative ?

Explain clearly why it is that in a thunderstorm (*a*) a downfall of rain tends to diminish the danger, (*b*) it is most unwise to hold up an umbrella in open country. [C.S.C.]

36. Describe the construction of an electroscope and an electrophorus. Explain how the latter may be used to charge the former. [C.S.C.]

37. Explain the action of a Leyden jar. In what ways are condensers of practical importance ?

38. State what you know of modern views concerning atoms and electrons.

39. How is lightning produced and how does a lightning conductor work ?

40. Describe a Wimshurst machine.

ANSWERS TO NUMERICAL QUESTIONS.

PHYSICS.

Mechanics, etc.

14. 4 feet from balancing point. **15.** 240,000 ft.-lb. **18.** 4·5.

Heat.

3. 1190. **6.** 21°·7 C.; −17°·8 C.; −40° C. **7.** 2·0066 m.
8. 1 litre. **24.** 20 gm. **26.** 739 approx.

Light.

18. 36 cm. in front of mirror, and the image is three times as long as the object. **24.** −16 cm.

Electricity.

22. (*a*) $\frac{2}{3}$ amp.; (*b*) $\frac{1}{6}$ amp. **25.** $\frac{5}{11}$ amp.; 484 ohms.
26. 285·7 ohms; 0·35 amp.

PART III

CHEMISTRY

MAN'S USE OF MATTER

CHAPTER XXXIII

THE ATMOSPHERE AND OXYGEN

Our active existence consists very largely of our relations with the great variety of material things around us. There are many thousands of different kinds of material substances, but most people are familiar with relatively a few of them, such as iron, coal, wood air, water, etc. Every kind of substance, common or rare, useful or useless, is included in the general term **matter.** Sometimes matter is defined as that which occupies space, also as that which can be weighed, since the weight of any substance, even of gases, can be found if suitable apparatus is used. Physics is the study of matter in motion, but quite apart from man's use of motion, the various kinds of matter may be useful or otherwise because of their inherent nature. For example, the nature of the common metals copper and tin is such that they can be hammered into flat plates, drawn into fine threads, heated to a high temperature without melting, and they do not easily rust or corrode. These useful characteristics depend upon the inherent qualities of these metals. Again, one of the reasons why salt, sugar, and washing soda are useful is because they dissolve in water, a property due to inherent characteristics.

Chemistry is the study of matter, its nature, and the changes which it undergoes. It is the aim of the chemist to discover all

that can be known about the various kinds of matter, and of the ways in which any one kind may affect other kinds when brought into contact with them. In his investigations of matter the chemist follows the usual procedure of experiment and observation, and many facts concerning chemical procedure may be learned if this method be applied to the study of the air we breathe.

THE ATMOSPHERE

All around and above us, for perhaps some 200 miles, extends the gaseous substance called air, or the atmosphere. This light, invisible, and odourless gas is literally the breath of life for all living things, even fish and other aquatic creatures requiring air that is dissolved in water

That the air has weight is shown by a simple experiment. On one side of a chemical balance is placed a glass globe fitted with a tap (Fig. 287). The air is pumped out of this by means of an air pump and then the globe is carefully weighed by putting the necessary weights on the other pan of the balance. The weight being noted, air is admitted by turning the tap, and the globe is weighed again. The increase gives the weight of that volume of air occupying the vessel at the atmospheric pressure and temperature existing at the time when the experiment is performed. The volume of the globe can be ascertained, and it will be found that under average conditions of pressure and temperature 1000 cubic centimetres of dry air weigh 1·29 grammes. This volume, 1000 c.c., is found to be a very useful one in chemical work and is known as a **litre.**

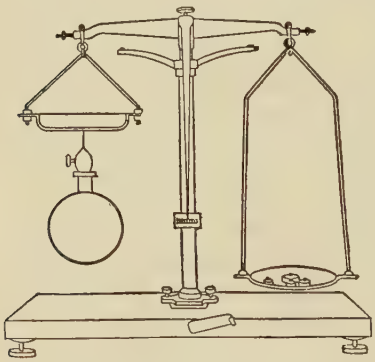


FIG. 287.
AN EXPERIMENT TO PROVE THAT AIR HAS WEIGHT.

Of what is the air composed? Is it one indivisible substance, or is it made up of more than one kind of matter, and if so, are these substances merely mixed together or united in some way? If some clean iron filings are sprinkled on the moistened interior surface of a tall glass jar, the open end of which is then placed in a trough of water, certain changes take place after some time (Fig. 288). Examination of the vessel, a day or two later, reveals that the filings have been converted to brown rust and that the water has risen in the vessel about *one-fifth* of the original air space. Three very important facts are obvious. The filings are no longer ordinary iron but have become something else, a part of the enclosed air has been used in the process, and that this part of the air formerly composed about $\frac{1}{5}$th of the original air. If a glass cover slip is placed over the mouth of the vessel, the latter can be removed from the water and placed with the covered mouth upwards. A lighted taper on being plunged into the residual gas ceases to burn. A taper burns in ordinary air, therefore the original enclosed air has been robbed of that part of it which enables things to burn, and a large proportion of air consists of a substance that does not allow things to burn. That part of the air which is necessary for the process of burning is called **oxygen** and the other part is known as **nitrogen.**

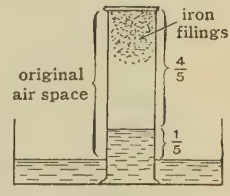


FIG. 288.
THE RUSTING OF IRON IN A CLOSED VOLUME OF AIR.

There is about four times as much nitrogen in the air as there is oxygen. In the experiment the iron has used the oxygen and formed with it a new substance commonly known as rust but in chemistry called **oxide of iron.** Rust is not like either iron or oxygen, though it contains both of them. It is not merely a mixture of iron and oxygen but a definite **compound** substance. Iron is simply iron and nothing else. We cannot divide a piece of pure iron into anything other than iron no matter how we may try to do so. Any simple substance that cannot be split chemically into two or more unlike substances is called an **element.** The common metals, and oxygen, sulphur, and carbon are examples of elements used in daily life. Each of these

substances resists all efforts to resolve it into dissimilar substances. On the other hand, rust can be robbed of its oxygen and reconverted to iron by heating it in a stream of coal gas. This process, of course, requires special apparatus. Rust is not an element but a compound, since it can be divided into its constituent elements. The vast majority of useful substances—wood, sugar, soap, oils, etc.—are compounds. There are, then, two great classes of substances, elements and compounds, and any one substance can be referred to one of these classes.

It must be clearly understood that in compounds the substances are chemically combined, not merely mixed together. *The air is merely a mixture of oxygen and nitrogen, not a compound.* It is not an oxide of nitrogen, though there are several oxides of nitrogen.

CHEMICAL AND PHYSICAL CHANGES

When oxygen combines with iron to form rust a **chemical change** takes place, and, as it so happens in this case, a **physical change,** a change of colour, also takes place. These two kinds of changes often occur together, but sometimes physical alterations take place without any accompanying chemical change. Heated lead melts, hot iron becomes red, and water becomes steam. These are physical changes only. Lead is still lead though molten, iron is still iron though red hot, and steam is chemically the same as water though in the gaseous state. On the other hand, since a chemical change means the formation of a new substance there is an alteration in weight: a physical change also takes place. If a substance alters in colour, or becomes liquid or gaseous during the process, then more than one physical alteration accompanies the chemical change.

OXIDATION

One of the results of the chemical process called oxidation is the formation of certain compounds consisting of oxygen and one other element only. Such compounds are known as **oxides.** Sometimes an element combines with oxygen in more than one proportion, giving rise to two or more oxides of the same sub-

stance. Thus, there are three well known oxides of lead, each having a different proportion of oxygen from that in either of the other two. There are two oxides of hydrogen, water being one: hydrogen peroxide, a valuable antiseptic, the other. Many oxides are of considerable use to the community, while others are a nuisance. The formation of rust on iron and steel objects is one of the most serious nuisances and means have to be taken to prevent such objects from rusting. Coatings of paint, enamel,

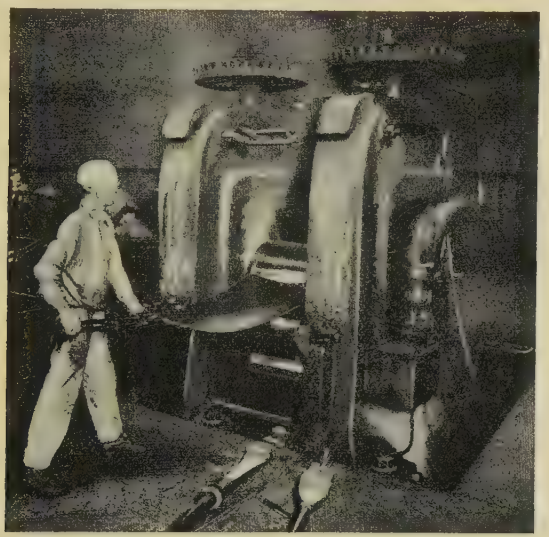


FIG. 289.—ROLLING STEEL SHEETS PREPARATORY TO TIN PLATING (DIPPING).

and grease are the chief means of rust prevention, and it is an interesting fact that paints form a protective crust because they themselves oxidise in 'drying.' Iron specially treated and called **galvanised iron** is of great use in the manufacture of buckets, wire netting, shed roofs, etc. The process of galvanising consists of first treating the iron with sulphuric acid and then with molten zinc, the final product being a metallic substance which resists both damp and oxygen. Steel plates may be treated in a somewhat similar way, though tin is used in place

of zinc and the product is known as **tinned plate** (Fig. 289). The tins used to contain domestic commodities are made of sheet iron that has been subjected to a tinning process.

Both moisture and oxygen are necessary for the formation of rust. Iron filings do not rust if they are placed in either dry air or in a flask of water from which the dissolved air has been displaced by boiling. Such metals as copper owe their utility partly to the fact that they do not oxidise even at high temperatures, hence their employment for such articles as kettles, etc. The alloy brass is valuable for a similar reason. Among the useful oxides are red lead, used by the plumber; zinc oxide, commonly known as 'white zinc,' employed as a pigment; oxide of sulphur, a valuable gaseous disinfectant; and oxide of carbon, a gas which dissolved in water constitutes the drink called soda water.

Oxidation is a process in which heat often plays a prominent part. Phosphorus and iron oxidise slowly at ordinary temperatures, but some other elements oxidise only under the influence of considerable heat.

COMBUSTION

Carbon and sulphur must be heated to a temperature at which they take fire before oxidation occurs. When oxidation or any other chemical change takes place at such a temperature that the substance burns, the phenomenon is called **combustion.** Thus we speak of the combustion of gas in a burner, of coal in a fire grate, and of hay in a rick when it bursts into flame on account of heat caused by fermentation. This last is a case of **spontaneous combustion,** the heat not being supplied by any external source.

In most cases of combustion, such as that in a coal fire, the chemical action once started produces the heat necessary for a continuation of the process. Chemical energy is then converted to heat energy, hence the great use of combustion in working locomotives and other machinery. Greater heat is obtained when combustion is more thorough than when it is incomplete, a principle employed in the use of the **bunsen burner**

(Fig. 290). Near the base of the burner is a hole for the purpose of admitting air. The amount of air admitted is regulated by a movable metallic ring containing another hole which, moving across the first one, varies the size of the aperture. When the aperture is correctly adjusted, sufficient air is admitted to permit thorough combustion of the gas, with the result that the maximum amount of heat is obtained in the flame, which is then of a dark purple tint. Close the hole and the flame becomes luminous, because many carbon particles in the flame are merely incandescent and are not being properly oxidised. The burner of a modern gas cooker makes use of the same principle; the air admitted through the holes mixes intimately with the particles of gas and facilitates thorough combustion.

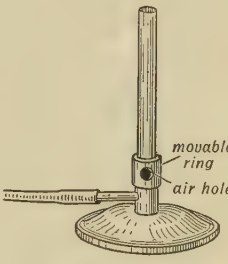


FIG. 290.—A BUNSEN BURNER.

The degree of combustion and its relation to luminosity can be appreciated by reference to the bunsen flame when the air aperture is adjusted in different positions (Fig. 291). With the flame partly luminous, several well-marked parts are distinguishable. At the base of the bunsen is a 'blue zone' where the temperature is relatively low, about 350° Centigrade. The head of a match can be quickly plunged into this zone and remain there without taking fire. Above the blue zone is a hotter luminous sheath consisting very largely of incandescent carbon particles derived from the decomposition of hydrocarbon gases in the coal gas. The outside portion of the flame consists of an almost non-luminous mantle having the highest temperature, about 1500° C. A candle flame exhibits a similar arrangement, a good one in this case since a luminous flame is desired. The inner dark zone is very pronounced in the old-fashioned gas jet. The modern incandescent mantle burner makes use of a bunsen effect, since air is admitted by means of a regulator at the base of the burner. The very high temperature obtained renders the mantle white hot, but owing to its nature it does not oxidise. These mantles are originally composed of a cotton fabric treated

with substances containing **thorium** and **cerium**, two of the rarer elements. The result is a fragile structure which is rendered fit for transport by being dipped in collodion. It is the collodion which is burnt off before the mantle functions properly.

In the case of certain inflammable substances sufficient heat for combustion may be obtained from friction. Matches consist of wooden strips dipped in sulphur or phosphorus together with a good oxidising agent such as potassium chlorate or oxide of manganese. This type of match will ignite when rubbed on any hard surface. The commonly used safety match is tipped with

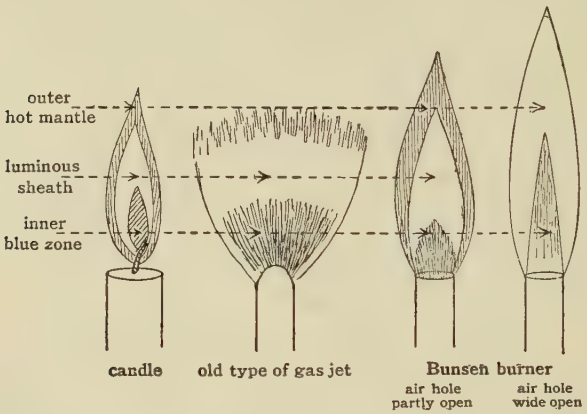


FIG. 291.—STRUCTURES EXHIBITED BY VARIOUS FLAMES.

a mixture of antimony sulphide and potassium chlorate, and this will ignite only when rubbed on the right material, consisting of red phosphorus and powdered glass placed in the sides of the match box. Substances like potassium chlorate rich in oxygen and ready to part with some of it are called **oxidising agents.** Nitre used in gunpowder is another and supplies oxygen for the very rapid combustion of the other constituents—sulphur and charcoal. The process of disinfection is often one in which organic matter is oxidised and thereby converted to a new harmless substance. The common oxidising agents used for this purpose are **hydrogen peroxide** and **sodium permanganate,** the latter dissolved in water is known as Condy's Fluid. Rapid

combustion is not always desirable, particularly in the case of certain domestic heating appliances. In an anthracite stove or in any of the numerous modern kitchen boilers, slow combustion is essential, and this is obtained simply by regulation of the air supply.

REDUCTION

When iron rusts, oxygen is absorbed and an oxide formed. The converse process, that of taking oxygen away from an oxide, is quite simply performed and is often of great use. Sometimes merely heat is required. When oxide of mercury is placed in a glass test tube and heated it decomposes, oxygen being evolved, and a film of mercury collects on the cooler end of the tube. A glowing splinter plunged into the tube while the oxide is being heated burns more brightly, showing that oxygen is being liberated. This process of taking oxygen away from oxides or from other substances containing oxygen is called **reduction.** In many cases heat alone is insufficient to bring about reduction, and in such cases some substance with a great attraction for oxygen, and called a **reducing agent,** must be used.

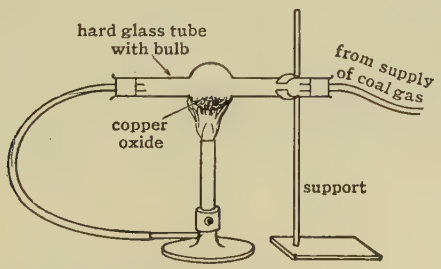


FIG. 292.
THE REDUCTION OF COPPER OXIDE BY MEANS OF COAL GAS.

The reduction process is much used in commercial life, particularly in the extraction of metals from their ores. If coal gas is passed over heated oxide of copper, certain constituents of the coal gas take the oxygen to form water vapour and oxide of carbon (Fig. 292). This operation is carried out by placing the black copper oxide in a tube of heat-resisting glass. The same gas that

is reducing the oxide can be passed forward to a bunsen burner producing the necessary heat. After twenty minutes or so a reddish-brown powder of metallic copper is all that remains inside the glass tube. Carbon is another good reducing agent since it takes up oxygen to form oxide of carbon, a gaseous product that escapes into the air.

If some oxide of lead is placed in a clean hole scraped in a piece of charcoal and then heated strongly by means of a blow-pipe, a bead of metallic lead is left on the charcoal.

PREPARATION OF OXYGEN

The usual laboratory process of obtaining oxygen for experimental purposes consists of the reduction of certain oxides or other substances by heat alone. It is usual to employ black oxide of manganese mixed with an equal portion of a white crystalline substance called potassium chlorate. About a tablespoonful of this ' oxygen mixture ' is placed in a wide glass tube fitted with a cork and glass tube which delivers the oxygen to a trough of water (Fig. 293). On the tube being heated, oxygen is evolved quickly, and the gas can be collected by displacement of water in cylindrical jars standing mouth downwards over an arrangement called a ' beehive ' in the trough.

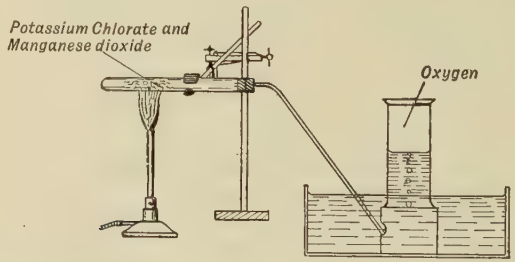


FIG. 293.—APPARATUS FOR THE COLLECTION OF OXYGEN.

When a jar is full of the gas a glass cover slip is placed over the mouth and the jar removed. A glowing splinter plunged into the oxygen burns very brightly, showing how easily things oxidise in the gas undiluted with nitrogen. A piece of charcoal which

just glows in ordinary air burns brightly when lowered into oxygen by means of a deflagrating spoon. Phosphorus burns very violently in oxygen, but if it is burned in a closed volume of air it supplies us with another means of proving that one-fifth of the air is oxygen and about four-fifths is nitrogen. The oxidation of iron is slow but that of phosphorus is rapid, and the results can be seen within a few minutes. A small piece of yellow phosphorus is placed in a crucible floating on water in a

FIG. 294.—CUTTING STEEL PLATE WITH THE OXYACETYLENE FLAME.

trough. Over the crucible is placed a bell-shaped glass jar. The phosphorus will commence to burn when touched by a hot wire, and dense white fumes of oxide of phosphorus are produced. These fumes dissolving in the water cause the latter to rise in the bell jar. When all the fumes have dissolved it is found that the water has risen about one-fifth of the original air space.

Oxygen in the right proportion is an absolute necessity to living creatures. Too much or too little oxygen produces harmful results. The oxygen of air breathed into the lungs combines

with certain substances in the blood, and the products of this cool combustion, carbon dioxide and water vapour, are brought out with the exhaled breath. In industrial life oxygen is used in many ways, such as the oxy-acetylene welding of metals, the production of limelight for projection lanterns, for the thickening of oils, and for bleaching purposes. Oxygen is colourless, tasteless, odourless, dissolves to some extent in water, is a little heavier than air, and can be liquefied at a very low temperature.

What about the nitrogen? A lighted taper will not burn in the gas. Nitrogen does not support combustion, neither does it combine easily with other elements to form compounds. Although nitrogen is so inactive as an element it is an essential constituent of several useful substances including ammonia, nitric acid, saltpetre and other nitrates valuable as soil fertilisers. The method of using atmospheric nitrogen in the formation of artificial nitrates for the purposes of land cultivation is explained in a later chapter. Small traces of other inactive gases occur in the atmosphere. The late **Sir William Ramsay** discovered **argon** in 1894, and later he isolated four other rare gases of a similar inert character—**helium, neon, krypton,** and **xenon.**

These gases are of use for ' gas filled ' electric lamps where air, since it contains oxygen, would cause a heated wire to oxidise.

LIQUID AIR

Liquid oxygen boils at the very low temperature of $-182{\cdot}5^{\circ}$ C., while nitrogen boils at -195° C., a few degrees lower. Hence if air can be cooled to a temperature below this latter figure it liquefies. Conversely if liquid air is allowed to evaporate, both gaseous nitrogen and oxygen are obtained, but since oxygen can remain a liquid at a slightly higher temperature than nitrogen, the latter comes away first, the oxygen later. Hence large quantities of oxygen for commercial purposes are now obtained from the evaporation of liquid air.

How is the very low temperature necessary for the liquefaction of air obtained? If a thermometer is held in the stream of air issuing from an inflated cycle tyre when the valve is loosened, a fall of temperature is observed. When

any gas under pressure passes through a small aperture into a region where the pressure is much less it expands considerably and at the same time its temperature falls.

The method of liquefying air is based upon this principle. Compressed air at a pressure about 200 times that of the atmosphere is cooled by water and then passed along a spiral tube having, at the further end, a small aperture operated by a needle valve (Fig. 295). The air in passing out of this aperture expands

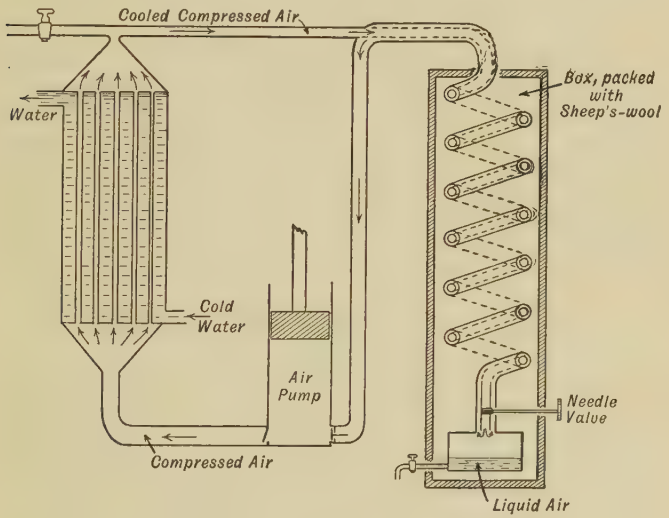


FIG. 295.—APPARATUS FOR THE LIQUEFACTION OF AIR.

and is very much cooled. This cooled air then proceeds along another tube, which fits as a jacket over the inner tube, and back to the pump to be compressed and used again. The air as it passes back along the outer tube has a further cooling effect on the on-coming air in the inner tube. In this way the air becomes colder and colder as it passes out of the orifice and eventually liquefies and is collected in a trough below the valve. Transference of heat from external objects to the apparatus is prevented by a packing of wool or other non-conducting material.

Liquid air or liquid oxygen must be kept in specially constructed vessels similar to the popular vacuum flask, so that heat from external sources cannot get to it and cause it to evaporate. When a liquid becomes gaseous there is an enormous expansion; consequently if ' cartridges ' of fibrous material are soaked in liquid oxygen and then fired by electricity, the expansive force can be utilised to blow up rocks in mining or quarrying operations.

CHAPTER XXXIV

HYDROGEN AND WATER

The lightest substance known is a colourless, odourless and inflammable gas called **hydrogen,** so named because its oxidation produces water (Greek *hydor* water, *gennao* I produce). Later, methods of inducing water to give up its hydrogen will be described, but for the present let us consider hydrogen itself, how a sample of it may be prepared, and what chemical and physical properties it possesses. Since hydrogen is present in any acid substance, the usual laboratory method of obtaining samples of the gas is to bring a common acid, such as dilute sulphuric, in contact with another substance capable of turning the hydrogen out of the acid. Some common metals such as zinc and iron are capable of doing this, consequently a little zinc is placed in a glass flask fitted with a rubber stopper through which pass two tubes, one called a thistle funnel, and used for pouring in the dilute acid, the other serving as a delivery tube, to pass the hydrogen forward to a pneumatic collecting trough similar to that employed for the preparation of oxygen. Hydrogen being only slightly soluble, it can be collected over water.

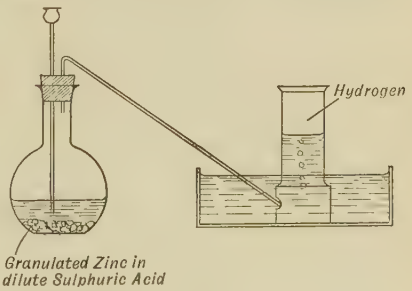


FIG. 296.
THE PREPARATION OF HYDROGEN IN THE LABORATORY.

A quantity of dilute sulphuric acid sufficient to cover the zinc is passed into the flask, and immediately, without warming

the apparatus, a brisk effervescence due to the liberation of hydrogen takes place. At first the air occupying the flask is displaced so that the hydrogen is not collected at once. When one or two jars of gas have been obtained the action is stopped by pouring water into the flask, and then emptying it of its contents.

If the cover slip is removed from one of the jars of hydrogen, and a lighted taper brought to it, the gas instantly takes fire, usually accompanied by a slight explosion, due to admixture with air near the mouth of the vessel. A mixture of hydrogen with air or oxygen is very explosive, and *on no account should a flame of any sort be brought near the generating apparatus.* The gas burns with a characteristic faintly luminous purple flame, and a film of moisture is deposited on the sides of the vessel.

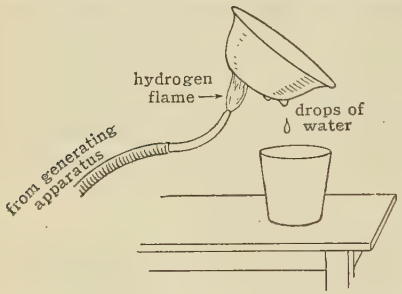


FIG. 297.

A METHOD OF SHOWING THAT WATER IS PRODUCED WHEN HYDROGEN BURNS IN AIR.

The burning of hydrogen produces an oxide of hydrogen commonly called **water.** The formation of water by this oxidation can be shown better if the hydrogen is burned at a jet, and some cold object, such as a porcelain evaporating basin, is held in contact with the flame (Fig. 297). Drops of water collect on the basin. When a lighted taper is brought to the mouth of a second jar of the gas held upside down, the gas burns more slowly, the flame gradually passing upwards. Hydrogen being very light tends to keep near the top of the inverted vessel. Since the air is about 14·5 times as heavy as hydrogen, the latter can be poured upwards from one vessel into another, the heavier air being displaced. The actual weight of a given volume of hydrogen at normal atmospheric pressure has been determined with great accuracy, *one litre, or* 1000 *cubic centimetres, of the hydrogen weighs* 0·08987 *gram.*

On account of its extreme lightness, it is much used for filling balloons and airships, though the slightly heavier gas called

helium is sometimes employed for this purpose, since it is non-inflammable.

Helium was discovered in the sun by means of the spectroscope, before its presence on the earth was observed, hence its name from *helios*, the sun.

Coal gas, also lighter than air, may be similarly employed. A balloon filled with any of these substances rises through air in much the same way as a piece of submerged cork when released rises through water.

Hydrogen used for balloons is not prepared by placing zinc in dilute acid, because the large quantity of zinc that would be necessary makes such a method far too expensive. By careful measurement of the weight of hydrogen liberated from a dilute acid by a known weight of zinc, it has been ascertained that to obtain 1 lb. of hydrogen, 32·5 lb. of zinc must be used. Thus, with any acid, 32·5 parts by weight of zinc must always be employed to obtain one part by weight of hydrogen, consequently **the figure 32·5 is known as the chemical equivalent of zinc.** The chemical equivalent of any element is that weight of it which is equivalent in chemical reactions to unit weight of hydrogen. If iron were used in place of zinc, very little advantage would be obtained, since the equivalent of iron is 28.

For these reasons some other method of obtaining hydrogen for aeronautical purposes must be employed. If steam is passed over heated iron, the latter combines with the oxygen in the steam, while the hydrogen passes on and can be collected. But commercial hydrogen is now mostly obtained as a by-product, in the preparation of a substance called **caustic soda**, used in the manufacture of soap and other useful chemicals. Both hydrogen and another gas called **chlorine** are obtained as by-products, and are stored in strong steel cylinders. The properties and uses of chlorine are described in a later chapter.

Though steam yields its hydrogen when in contact with heated iron, hydrogen is capable of taking oxygen from many substances; hence it is a good reducing agent. The reducing properties of coal gas, which contains hydrogen, were described in the previous chapter, and it is scarcely necessary to say that hydrogen may be used in place of coal gas if desired, when an

oxide of copper or other metal is to be reduced to the metallic state.

Hydrogen is an example of an element very active chemically, and thus differs from nitrogen. In hydrogen peroxide, a valuable antiseptic, we have another oxide of hydrogen in which the proportion of oxygen is higher than it is in water.

THE COMPOSITION OF WATER

The liquid called water is of such universal importance that it is scarcely possible to mention here all the various ways in which it serves mankind. Living things, both plants and animals, cannot exist without it; enormous shipping, fishing, and other industries result from the fact that three quarters of the earth's surface consists of sea water; and, in addition, there is the great volume of fresh river and lake water so necessary to human beings and other creatures not inhabiting the sea. Water is an essential part of a large number of substances, including sugar, starch, fats, and washing soda, and on account of its solvent action it is necessary in a great many commercial and other processes.

With soap it forms an emulsion capable of removing dirt and grease from clothing, etc. Steam power is derived from water, and other mechanical power is obtained from falling water, as at Niagara, where electricity is generated on a very large scale.

As we have seen above, water is produced by the oxidation of hydrogen, and is an oxide of hydrogen. All experiments which have been performed upon pure water show that it consists simply of hydrogen and oxygen; only in impure water are other elements present.

Are there any other ways of obtaining hydrogen from water, apart from passing steam over heated iron? If a very small piece of the soft, grey lustrous metal called **sodium** is placed on water in an open dish, there is a brisk effervescence due to escaping gas, and the floating sodium is driven rapidly from place to place upon the surface of the water. When a lighted taper is placed near the sodium, the escaping gas burns with a yellowish flame due to sodium vapour mixing with the hydrogen.

Since sodium itself contains no hydrogen, the latter must come from the water. A related metal known as **potassium** acts in the same way as sodium, but in that case the chemical action is so brisk, and the heat disclosed so considerable, that the liberated hydrogen takes fire without the application of a lighted taper. The sodium (or potassium) disappears and the action ceases.

Where has the metal gone? Most of it has not been vaporised but has formed a new compound substance with the remaining portion of the affected molecules of water, and this new substance is caustic soda, which dissolves in the rest of the water, forming a solution which turns red litmus paper blue. Litmus is a vegetable substance that is turned blue by alkaline materials, hence the solution of caustic soda is alkaline, and for this reason sodium (and potassium) itself is known as one of the alkaline metals. It is interesting to note that sodium and potassium rapidly oxidise in air, hence they are kept under oil. The compounds of these metals are very important commercially, and more will be said about them in a later chapter.

Now, in addition to sodium, caustic soda contains oxygen and hydrogen, both obtained from the water, and this being so, it is clear that all of the hydrogen was not liberated from those molecules of water that reacted with the metal. Hence the contact of an alkaline metal with water shows that the liquid contains hydrogen (and oxygen since caustic soda is formed), but does not demonstrate the actual proportions of these elements in water.

The proportion by volume of hydrogen and oxygen in water can be shown by electrical means, employing an instrument called a **voltameter** (Fig. 298). This consists of three tall glass tubes, a central one acting as a reservoir of water, while the two side tubes function as collecting vessels, one for hydrogen, the other for oxygen liberated from the water.

An electric current from a battery is passed into one tube by means of a rubber bung fitted with a platinum plate or **electrode** and is conducted out of the apparatus by another similar platinum electrode inserted in the base of the other tube. Now, ordinary pure water will not permit a current of electricity to pass, but if a little dilute sulphuric acid is added the solution becomes an

electrolyte capable of passing the current from one electrode to the other. As the current proceeds through the solution, gases collect in the two tubes, but that in the tube having its electrode connected to the *negative* terminal of the battery collects at twice the rate of the gas in the other tube connected with the positive battery terminal marked +. At the end of some minutes a con-

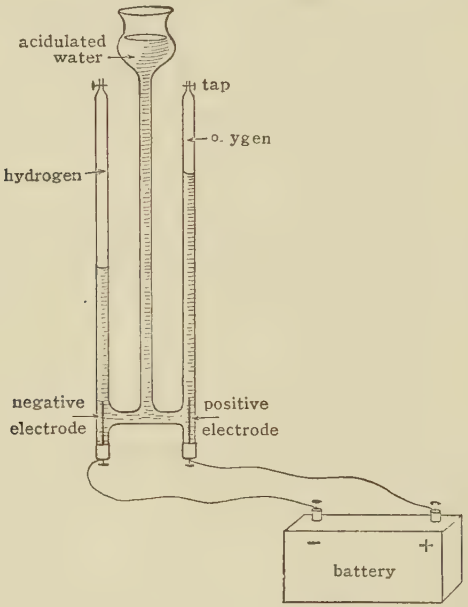


FIG. 298.—THE ELECTROLYSIS OF ACIDULATED WATER IN HOFFMAN'S VOLTAMETER.

siderable volume of gas has been collected, and by means of a tap at the top of each tube, the contained gas can be tested by a glowing splinter. That occupying the larger volume is found to be inflammable, and burns with a purple flame, hence it is the liberated hydrogen. The other gas does not itself burn, but rekindles the glowing splinter; it is oxygen. This process of **electrolysis** shows that so far as volume is concerned water contains twice as much hydrogen as oxygen. But the composi-

tion of water by weight is very different, since hydrogen is the lightest known substance and oxygen is about sixteen times as heavy as hydrogen.

The proportion by weight of these gases in water was first determined by the French chemist, **Dumas** (1800-1884), who also discovered accurate means of determining the densities of vapours. He became well known as a teacher and investigator, and later took an active part in politics, becoming Minister for Agriculture and Master of the French Mint.

Now, the electrolytic process is **analytical** in character, since it supplies information concerning water by separating its con-

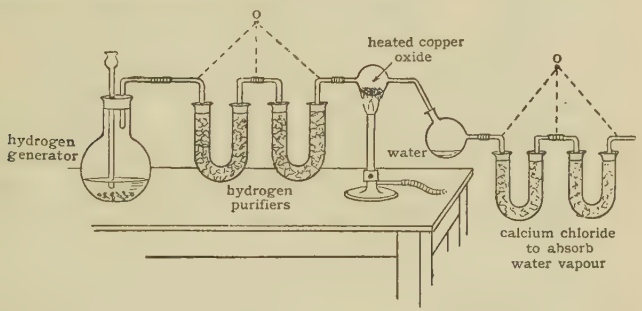


FIG. 299.—APPARATUS ARRANGED TO DETERMINE THE COMPOSITION OF WATER BY WEIGHT.
(DUMAS' EXPERIMENT.)

stituent elements, but it is possible to bring these elements, hydrogen and oxygen, together (as when hydrogen burns) and make them combine to produce water. This building-up process or **synthesis** was the mode adopted by Dumas, who passed hydrogen over heated copper oxide contained in a suitable glass vessel. (Fig. 299). The hydrogen robbed the oxide of oxygen, and the water vapour which passed over was condensed to water and collected in a vessel of known weight. The copper oxide was previously weighed, and its subsequent loss in weight gave the weight of oxygen used to produce the weight of water collected; then, by subtraction, the weight of hydrogen was calculated. As some water might escape in the form of uncondensed vapour, a series of tubes containing calcium chloride, a substance capable

of absorbing water vapour, was included in the apparatus and the increase in weight noted. The estimation required very careful weighing, and the hydrogen was made as pure as possible by passing it through substances capable of absorbing impurities before it came in contact with the copper oxide.

The results obtained by Dumas showed that the proportion by weight of hydrogen and oxygen were represented by the figures 2 and 15·96 respectively, that is, in every 17·96 grams of pure water there are 2 grams of hydrogen and 15·96 grams of oxygen. Several other chemists have performed very careful experiments since the time of Dumas, and **Morley,** an American chemist, who experimented upon this matter for twelve years, has shown that the relative proportions by weight are more correctly stated as **hydrogen 2 and oxygen 15.879.** Approximately $\frac{8}{9}$ of the weight of pure water is due to oxygen.

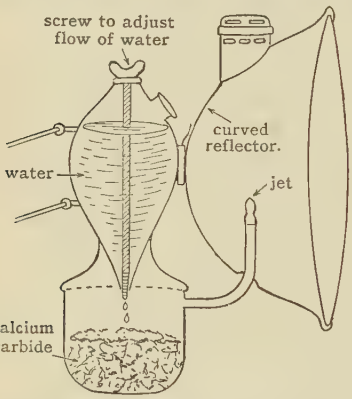


FIG. 300. — VERTICAL SECTION THROUGH AN ACETYLENE CYCLE LAMP.

Among the properties of water which make it useful are the following: its liquid form at ordinary temperature, the formation of steam at the moderate temperature of 100° C. or 212° F., the production of ice at the temperature of 0° C., or 32° F., its powerful action as a solvent, its chemical stability in the presence of most other substances at ordinary temperatures, the very slight compressibility which enables pressure to be easily transmitted through it, the density which makes shipping possible, its weight, and its power of reacting chemically with one or two substances at ordinary temperatures. As an example of the last-mentioned property, its action on **calcium carbide** should be noted. The highly luminous inflammable gas **acetylene,** employed in many motor-cycle lamps, for luminous buoys at sea, and for the country house lighting, is produced by water dripping at a regular

rate upon calcium carbide. This reaction is a case of **double decomposition,** each of the substances decomposing the other. Though equations employing chemical symbols are explained in the next chapter this reaction may here be explained by an equation expressed in words:

Calcium carbide + water yields lime and acetylene.

There is a general interchange of partners in the molecules. Calcium leaves the carbide and oxygen leaves the water. The elements rearrange themselves with the production of acetylene and lime.

SEA, RIVER, AND SPRING WATERS

A very large number of substances dissolve in water forming solutions. Among the common examples are sugar, salt, washing soda, borax, alum, and saltpetre. The vast deposits of saltpetre in the ground of Northern Chile remain undissolved because of the absence of rain.

A soluble substance occupies the minute spaces between the molecules of water, and when all of these spaces are occupied the solution is saturated. By the simple process of boiling the water away, the substances dissolved can be regained as a residue in the evaporating basin in which the simple operation is performed. In this way, not only can the kind of matter dissolved in water be determined, but the weight of it in a given weight of solution can be estimated. If a sample of average sea water is examined in this way, it is found that in 1000 parts by weight of solution there are 35 parts of dissolved solids, and the **salinity** of average sea water is said to be 35 per mille. Some seas are much more salt than others, those of warmer regions, where the supply of river water does not keep pace with loss by evaporation, having the highest degree of salinity. Thus the waters of the Mediterranean and Red Sea are among the saltest and therefore the most dense in the world, whereas those of the Baltic contain a relatively low proportion of dissolved matter.

Temperature exerts a big influence upon salinity, since warm water can dissolve more salts than cold water. Evaporation is also considerable in warm regions, consequently the salinity

increases unless the supply of river water keeps pace with it. This explains the occurrence of salt lakes, like the Great Salt Lake in North America, and such lakes, in time, become quite dry, leaving the salts as a thick deposit on the ground.

Many millions of years ago salt lakes existed in Cheshire and Worcestershire, and by the drying up of these, and the subsequent burial of the residue under more recent rocks, thick seams of **rock salt** are now found below the surface of the ground (Fig. 135). At Stassfurt in Germany similar large salt deposits containing chlorides and sulphates of potassium and magnesium occur, and are extensively worked for the metals and potassium sulphate obtained from them.

Though the degree of saltness or salinity of various seas is different, the kinds of salts dissolved are generally the same, and their relative proportions are fairly constant. Of the salty residue obtained when any sample of sea water is evaporated, about 78 per cent. is ordinary common salt, or **sodium chloride,** which explains the usual taste of sea water. Magnesium chloride is a very bad second, forming between 10 and 11 per cent., while the remainder is composed of magnesium sulphate, calcium and potassium sulphates, and magnesium and calcium carbonates, the calcium salts supplying the lime material used by marine creatures for building their shells and other hard parts. Traces of magnesium bromide and other salts are also present.

With regard to the origin of salts in the sea, it is generally believed that when the earth cooled sufficiently to permit steam to condense and form the first oceans, salty vapours also forming part of the early atmosphere dissolved in the waters, and have remained there ever since.

HARD AND SOFT WATERS

River water and that of most lakes contains a much smaller proportion of dissolved matter than that in sea water, the average salinity of rivers being only 0·018, or 18 parts by weight of salts in 100,000 parts of solution. The amount of matter dissolved depends to some extent upon the volume of water in the river, but

the chief factor determining salinity is the kind of rock over which the water flows. Clay and sandstone being practically insoluble, rivers draining country composed of such rocks, most of North Wales for example, are relatively pure, and the water is described as **soft**, since such water quickly forms a lather with soap. On the other hand, water draining a limestone region, such as central Derbyshire, dissolves the calcareous matter or lime compounds, and in consequence becomes **hard**, and a lather is not easily formed with soap. The slow evaporation of such

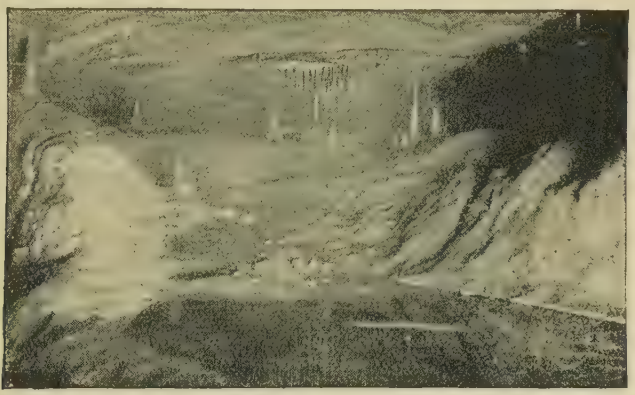


FIG. 301.—STALACTITES (ON THE ROOF) AND STALAGMITES (ON THE FLOOR).
IN CLAPHAM CAVE, YORKSHIRE.

water in caverns produces hanging pillar-like deposits or stalactites composed of calcium carbonate. It must be noted that, should a river obtain lime compounds at any part of its course, its water will be hard both at that part and in lower parts of the course nearer the sea. Some Wealden rivers which commence in sandstone and later pass through chalk are examples.

The substances which account for hardness of water are mainly compounds of calcium, particularly the soluble bicarbonate formed by the action of rain water and carbon dioxide from the air on limestone. Sodium compounds in solution do not matter, since soap itself is a compound of the same metal, chiefly sodium oleate, and there is consequently no chemical reaction. But

with the calcium compounds it is different; the soap reacts with them before it becomes available for forming a lather.

To soften water, the calcium compounds must either be precipitated, that is, thrown out of the solution, or converted to harmless sodium compounds. The bicarbonate of calcium can be precipitated by boiling the water, when the ordinary insoluble calcium carbonate is produced and thrown out of solution.

This is the reaction responsible for the formation of ' fur ' in a kettle or boiler, and hardness which can be eliminated in this

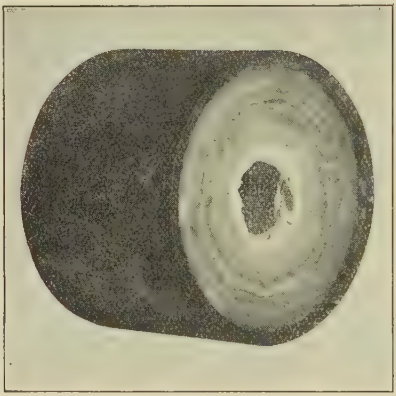


FIG. 302.
A THICK DEPOSIT OF ' FUR ' OR CALCIUM CARBONATE IN A HOT WATER PIPE.

way is described as **temporary.** But this will not do for locomotive boilers, where a deposit of ' fur ' is undesirable; it is not always convenient to boil water previously for domestic purposes, and certain kinds of hardness cannot be eliminated by boiling. Something more satisfactory is necessary. In **Clarke's process,** often employed at water works, etc., the water is placed in large tanks and lime is added. This converts the soluble calcium bicarbonate to the ordinary insoluble carbonate, which is thus precipitated as a solid. But there is a form of hardness which is not merely temporary, and in so-called **permanent** hardness, due to calcium salts other than the bicarbonate, some compound is added which, reacting with the calcium salts, forms new insoluble

substances which are precipitated. For this purpose, washing soda, a crystallised carbonate of sodium, is added to the water, and a typical case may be expressed by an equation employing words without symbols :

Calcium Sulphate +	Washing Soda produce	Ordinary Calcium Carbonate
(cause of hardness)		(precipitated)
		+ Sodium Sulphate
		(harmless)

This is another case of double decomposition, the various elements rearranging themselves with the formation of new substances, and this is just what is required.

In many commercial processes water is softened by the **permutite** process, which consists of filtering the water through a sandy artificially produced silicate of sodium and aluminium called permutite. The sodium changes places with calcium in the water, forming harmless sodium salts, but the sodium can again be restored to the permutite by treatment with salt solution, hence the same material can be used indefinitely.

Though mineral substances in solution are commonly a nuisance it is not always so. A certain amount of calcareous matter in drinking water is desirable for the formation of bones. There are many **mineral springs** containing compounds which are of considerable value medicinally. Chalybeate springs contain iron carbonate and possess tonic properties, others have dissolved sulphur compounds, beneficial in liver complaints, others contain iodine, and so on. The presence of these medicinal springs has produced numerous health resorts, or **spas,**[1] such as **Harrogate, Bath, Tunbridge Wells,** etc., where various *hydropathic* establishments give water treatment externally as baths as well as internally as medicines.

Really pure water is a rare thing in nature, the nearest approach being rain water, but even this obtains carbon dioxide and other substances as it falls through the air. Pure distilled water, necessary for the preparation of medicines and solutions in the laboratory, is obtained by **distillation,** that is, by boiling

[1] Named from the oldest of watering-places, Spa in Belgium.

and then condensing the steam (Fig. 303). No impurities of any kind pass over with the steam.

So far, we have considered only impurities in solution, but there are others occurring merely in suspension, that is, as insoluble particles floating in the water. Particles of clay and sand and some organic or living matter may be separated from the water by **filtration,** in which the water passes through a porous material but the suspended matter is prevented from passing. Though beds of gravel may be employed as a filter on a large scale, this will not do for the separation of the more minute forms

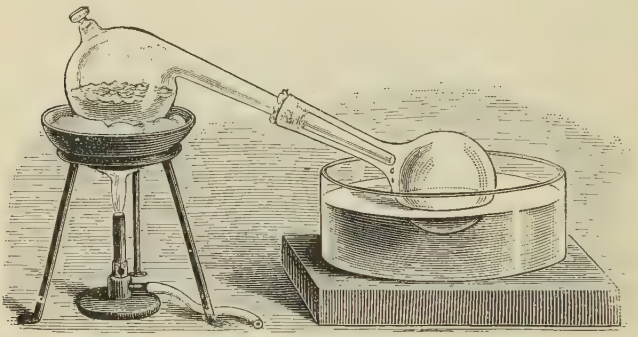


FIG. 303.—THE DISTILLATION OF WATER.

of matter, such as bacteria or germs of various kinds. In the **Pasteur filter** the water is made to pass through a porous cylinder of unglazed earthenware, which forms an effective barrier to the bacteria, etc. When large quantities of water are to be purified, a process known as the **coagulation treatment** is employed. Such substances as alum and lime are added, and, in consequence, slimy precipitates are formed which cause the suspended matter and bacteria to settle at the bottom of the large reservoirs in which the process takes place.

CHAPTER XXXV

QUANTITATIVE CONSIDERATIONS

When two or more elements combine to form a compound substance, do they always combine in fixed relative proportions by weight? For example, is water always composed of hydrogen and oxygen in the proportions 2 and 15·879 respectively? Careful quantitative analysis, that is, accurate estimation of the relative weights of hydrogen and oxygen in water, shows that these proportions always hold good for any sample of pure water.

Consider another case. Hundreds of samples of copper oxide have been accurately analysed, and the result has been always the same: 63 parts by weight of copper always combine with 16 parts by weight of oxygen in this particular oxide of copper.

Again, the unpleasant smell of a rotten egg is due to a gas called hydrogen sulphide, and this substance is always found to consist of 2 parts by weight of hydrogen combined with 32 parts of sulphur. Analyses of other compounds illustrate the same fact, usually expressed by **the law of fixed proportions,** which states that *in any compound substance the combining elements are always present in definite fixed proportions by weight*, and that in any pure sample of the same compound these proportions are always the same.

At the present time there is one known exception to this rule. In the substance called lead chloride the proportion of lead is not always the same. Ordinary lead chloride contains 207 parts by weight of lead combined with 71 parts of chlorine, but in lead chloride obtained from ores containing radio-active substances the proportion of lead varies between 206 and 208 parts. In time other exceptions to the rule of fixed proportions may be discovered, but in almost all compounds the rule holds good, and

it is fortunate that it is so. If the proportion of elements in substances were not fixed, but subject to considerable variation, many commercial chemical processes would be much hampered, if not impossible. One or two examples will suffice to show the great influence of the law of fixed proportions upon everyday life.

In the last chapter it was shown that the luminous gas acetylene is produced by the reaction of water with calcium carbide, and the composition of carbide is such that 64 parts of it by weight yield 26 parts of acetylene, provided of course that the requisite quantity of water is added. Now, if the proportion of calcium and carbon in the calcium carbide varied considerably, it would be impossible to ensure a supply of 26 parts of acetylene from 64 parts of carbide, and the supply of gas would be very erratic. House lighting, etc., would be subject to variations over which there would be no control. A similar result would occur if the composition of water were not according to fixed proportions of hydrogen and oxygen. Again, a physician's prescription made up by a pharmaceutical chemist might be ineffective, or even dangerous, if any ingredient had other than a fixed composition.

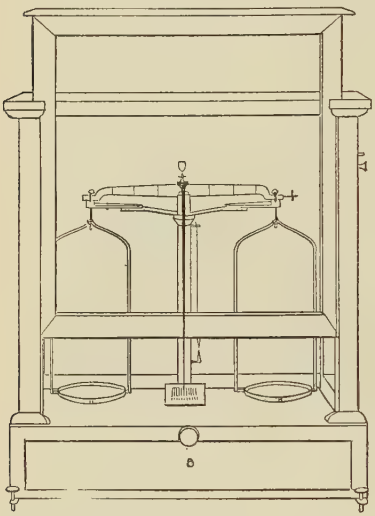


FIG. 304.—A CHEMICAL BALANCE.
THE GLASS CASE PREVENTS AIR CURRENTS FROM EXERTING ANY INFLUENCE UPON THE PANS OF THE BALANCE.

One good reason for our considering the air to be a mixture of oxygen and nitrogen, and not a compound, is that different samples of air give different proportions by weight of these elements. Air does not conform to the law of fixed proportions.

It frequently happens that the same two or more elements combine in different proportions forming different compounds.

Thus hydrogen and oxygen combine to form the liquid called hydrogen peroxide, a substance distinct from water, and having a higher proportion of oxygen than water has. Analyses of hydrogen peroxide show that in it 2 parts of hydrogen combine with 31·758 parts of oxygen; the proportion by weight of oxygen is just double that of oxygen in water. The composition of many other compounds illustrate similar facts. In addition to ordinary copper oxide, there is another *suboxide* of copper in which 126 parts by weight of copper are always combined with 16 parts of oxygen. There are three common oxides of lead in which the relative weights of lead and oxygen, as found by analysis, are as follows: Litharge or yellow oxide of lead, lead 207, oxygen 16; red lead used by plumbers, etc., lead 621, oxygen 64; brown lead peroxide, lead 207, oxygen 32.

If the lead proportion 207 be represented by the symbol Pb (abbreviated form of Plumbum, the Latin name for lead) and the oxygen proportion 16 be represented by O, the composition of the three oxides can be expressed by the formulae PbO, Pb_3O_4, and PbO_2 respectively. These are actually the recognised chemical formulae for these oxides, and more is said about this later. These examples, chosen from hundreds that could be selected, serve to illustrate **the law of multiple proportions,** which states that *when the same two or more elements combine to form more than one compound the relative proportions of each element in the various compounds are simple multiples of the lowest proportion of the same element,* and can be expressed by small whole numbers. Thus in the oxides just considered, the relative proportions of lead are as the figures 1, 3 and 1, while those of oxygen are as 1, 4 and 2.

The law of multiple proportions was discovered by **John Dalton** (1766-1844), a Quaker schoolmaster, whose earlier years were spent in the Lake District, though his chief work and activities were connected with Manchester.

THE ATOMIC THEORY · ATOMS AND MOLECULES

As an explanation of the facts expressed by the laws of definite and multiple proportions, Dalton formulated his **atomic theory,**

which has become one of the fundamental conceptions of modern chemistry. According to this theory every element is composed of extremely small indivisible units called **atoms,** a name which signifies 'that which cannot be divided.' Every atom of an element is similar and has the same properties as other atoms of the same element. Though we now know that atoms are not simple structures, and that some of them disintegrate or break up, Dalton's theory still stands as a useful working hypothesis capable of explaining the formation of compounds by the union of atoms of various elements. According to the theory a fraction of an atom cannot exist, hence an element is present as a definite (and usually small) number of atoms, 1, 2, 3 and so on. Since every atom of the same element has the same weight, this explains the simple multiple proportions such as those of lead and of oxygen in the lead oxides considered above.

Now, in most cases single atoms do not exist by themselves in a *free* state; they combine to build up larger bodies to which Dalton gave the name of **molecules.** Thus one atom of lead combines with one atom of oxygen to form one molecule of litharge. Each element has a name and a corresponding symbol, the symbols for lead and oxygen being Pb and O respectively. By the combination of these the formula for litharge is written PbO, which means the same as Pb_1O_1. Small figures following the symbol for an element signify the number of atoms of that element present in one molecule of the substance. Red lead consists of three atoms of lead combined with four atoms of oxygen, hence the formula for one molecule of red lead is Pb_3O_4. Lead peroxide has a composition expressed by the formula PbO_2. A molecule of water contains two atoms of hydrogen and one atom of oxygen, hence its formula is H_2O, but in the case of hydrogen peroxide the formula is H_2O_2, since an extra atom of oxygen is present.

These substances are examples of compounds, but elements also exist in molecular form, as when free or uncombined hydrogen or oxygen is prepared in the laboratory. The molecule of hydrogen contains two atoms and its formula is H_2, not 2H, which would mean two molecules, each being composed of only one atom. Large numbers in front of a

symbol indicate the number of molecules. The molecular formula for oxygen is similarly O_2. More rarely a single atom can exist in the free state and form a molecule by itself; this is the case of many metals. Thus one atom is also one molecule of mercury and its formula is written Hg from the Latin word for mercury, Hydrargyrum.

ATOMIC WEIGHTS AND VALENCY

A brief description of the light thrown upon the subject of atomic structure by **Rutherford, Soddy,** and others, is reserved for a later chapter, but certain other facts concerning atoms must be considered here.

It is a matter of common knowledge that all forms of matter are not equally heavy; a cubic foot of iron is much heavier than a

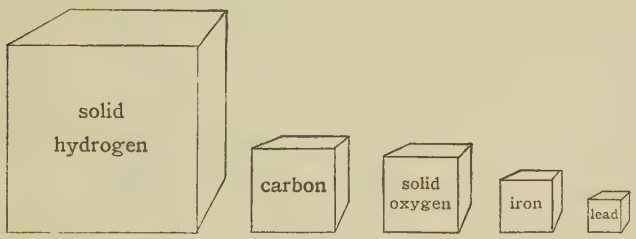


FIG. 305.

THE RELATIVE VOLUMES OF EQUAL WEIGHTS OF CERTAIN SUBSTANCES, ASSUMING ALL OF THEM WERE SOLID AT THE SAME TEMPERATURE.

similar volume of water. If this is true of large volumes it is also true of minute units. A molecule of iron is heavier than a molecule of water. Atoms of different elements also differ in their respective weights. In the measurement of anything some standard of reference is required, and in chemistry **the weight of an atom of hydrogen** can be taken as the standard, the respective weights of the atoms of all other elements being expressed in terms of it. Thus we have **atomic weights,** and when it is stated that the atomic weight of iron is 56, it is meant that the atom of iron is 56 times as heavy as the atom of hydrogen.

A discussion of the means by which these atomic weights have been accurately determined is beyond the scope of this book, but the results of such estimations must be given.

Though hydrogen is the natural standard for comparison, since it is the lightest substance known, for certain reasons it is preferable to adopt oxygen with an atomic weight of 16 as the standard. Oxygen combines to form a much larger number of common substances than hydrogen does, and the atomic weights of a larger number of elements approximate more closely to whole numbers when oxygen is taken as the standard. In the table given below the atomic weights of the more common elements are given with reference to oxygen as recommended by the International Committee on Atomic Weights.

Element	Symbol	Atomic Wt.	Element	Symbol	Atomic Wt.
Aluminium	Al	27·1	Magnesium	Mg	24·32
Antimony	Sb	120·2	Manganese	Mn	54·93
Arsenic	As	74·96	Mercury	Hg	200·6
Barium	Ba	137·37	Nickel	Ni	58·68
Bismuth	Bi	208	Nitrogen	N	14·01
Bromine	Br	79·92	Oxygen	O	16
Calcium	Ca	40·07	Phosphorus	P	31·04
Carbon	C	12·005	Platinum	Pt	195·2
Chlorine	Cl	35·46	Radium	Ra	226
Copper	Cu	63·57	Silicon	Si	28·3
Fluorine	F	19	Silver	Ag	107·88
Gold	Au	197·2	Sodium	Na	23
Helium	He	4	Strontium	Sr	87·63
Hydrogen	H	1·008	Sulphur	S	32·06
Iodine	I	126·92	Tin	Sn	118·7
Iron	Fe	55·84	Tungsten	W	184
Lead	Pb	207·2	Uranium	U	238·2
			Zinc	Zn	65·37

In calculations which follow in this and later chapters the atomic weights are mostly given as whole numbers for the sake of simplicity, and it must be understood that the results obtained are approximate values.

The **molecular weight** of a substance is found by adding together the weight of the atoms which are combined to form a molecule of the substance. Thus, in the case of water, the molecular weight is 18, obtained by adding twice the atomic weight of hydrogen to

once the atomic weight of oxygen according to the formula H_2O. The molecular weight of red lead Pb_3O_4 is

$$(3 \times 207 + 4 \times 16) = 685,$$

and similarly with other compounds. Note that the molecular weight of hydrogen H_2 is 2, and that of oxygen O_2 is 32. In the case of monatomic molecules such as that of zinc, both the atomic and molecular weights have the same value.

There is another quantitative relation that must be noted. In chemical reactions one atom of some elements can replace or take the place of only one atom of hydrogen; such elements, for example, the metals sodium and potassium, are said to be **monovalent.** Their **valency** or *chemical value in terms of hydrogen* is one. But many are **divalent,** or have a valency of two, since one atom of such substances, for example zinc, takes the place of two hydrogen atoms; others have a valency of three, such as aluminium, and still other elements exhibit higher valency than this.

Relatively a few elements exhibit more than one valency according to the compounds formed. Thus iron replaces two atoms of hydrogen and is therefore divalent in ordinary ferr*ous* sulphate, commonly called green vitriol, but in ferr*ic* sulphate it is trivalent or replaces three atoms of hydrogen. Other common elements which have more than one valency are sulphur, nitrogen, tin, and phosphorus.

There is, of course, a definite relation between the equivalent weight of an element and its valency. In the previous chapter it was noted that 32·5 grams of zinc are equivalent chemically to one gram of hydrogen, but the atomic weight of zinc is 65 (approx.), hence the equivalent weight of a divalent element is equal to half its atomic weight. Similarly, the equivalent weight of a trivalent element is equal to one third of its atomic weight. In the case of a monovalent element, its equivalent weight is numerically the same as its atomic weight.

CHEMICAL EQUATIONS AND CALCULATIONS

It is necessary to consider in more detail chemical formulae and the ways in which they are helpful in describing the precise

nature of chemical changes. As a typical example of a simple chemical reaction, that employed for the preparation of hydrogen in the laboratory may be taken. The materials used are zinc and dilute sulphuric acid; the formula for the former is Zn, and that for the latter is H_2SO_4. The significance of Zn is obvious enough, but what exactly does H_2SO_4 mean? This formula means that one molecule of sulphuric acid is composed of two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen, all combined together forming a definite compound. Two molecules of sulphuric acid are represented by $2H_2SO_4$. Now, the reaction of zinc with this acid may be expressed in words thus:

Zinc in contact with Sulphuric Acid produces Zinc Sulphate and Hydrogen.

This expressed in symbols is

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2.$$

The formulae show quite clearly the replacement of hydrogen by zinc with the resulting formation of zinc sulphate, and all substances derived from sulphuric acid by the replacement of the hydrogen by a metal are called **sulphates.** The equation tells us a good deal more than this about the reaction. It will be noted that in this case one molecule of each substance is required at a time; also the molecule of hydrogen contains two atoms while that of zinc contains only one, yet this one of zinc replaces the two of hydrogen; hence zinc is a divalent element. If the equation is rewritten with the respective molecular weights inserted other facts become apparent.

$$\begin{aligned} Zn + H_2SO_4 &\rightarrow ZnSO_4 + H_2 \\ 65 + 98 &= 161 + 2. \end{aligned}$$

Sixty-five parts by weight of zinc and ninety-eight parts of sulphuric acid are required to produce only two parts of hydrogen, hence this method is not an economical one for producing large supplies of hydrogen, as mentioned in the last chapter, where it was stated that 32·5 parts of zinc are chemically equivalent to one part of hydrogen.

Is any advantage gained if another acid, say hydrochloric, is used in place of sulphuric? The formula for hydrochloric acid is HCl and the equation representing the reaction is :

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$
(Zinc chloride).

$$65 + 2 \times 36{\cdot}5 = 136 + 2$$

Thus there is a slight economy in weight of acid required and that is all. Note that in this reaction two molecules of hydrochloric acid are necessary, since one atom of zinc replaces two of hydrogen, and that the compounds formed by replacing hydrogen in this acid by a metal are called **chlorides.** By reference to these equations it will be observed that the weights of matter involved total the same on either side of the equation, and this is as it should be since no form of matter can be destroyed. Every atom of substance must be accounted for.

We are now in a position to consider the quantitative aspect of the reaction which occurs when sodium is placed upon water.

Sodium in contact with water produces caustic soda and hydrogen :

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$
$$2 \times 23 + 2 \times 18 = 2 \times 40 + 2$$
$$46 + 36 = 80 + 2.$$

Two molecules of each substance are concerned except in the case of hydrogen. The equation

$$Na + H_2O \rightarrow NaOH + H$$

is incorrect, since one atom of hydrogen does not form a molecule or free particle; there are two atoms in the hydrogen molecule.

Equations must not only balance arithmetically, they must also interpret chemical facts correctly.

Observe that the sodium turns out only half the hydrogen of the molecules of water which react with it, a fact mentioned but not explained fully in the previous chapter. Since one of sodium replaces one of hydrogen, sodium is monovalent.

Oxygen can be prepared by heating certain substances, notably potassium chlorate, $KClO_3$.

$$\underset{\text{Potassium chlorate}}{2KClO_3} \rightarrow \underset{\text{Potassium chloride}}{2KCl} + \underset{\text{Oxygen}}{3O_2}$$
$$2 \times 122{\cdot}5 = 2 \times 74{\cdot}5 + 3 \times 32.$$

The equation must not be written :

$$KClO_3 \rightarrow KCl + O_3,$$

since O_3 represents the composition of **ozone**, a disguised form of oxygen, and in this reaction ozone is not produced. Neither can the equation be written $KClO_3 \rightarrow KCl + 3O$, since $3O$ suggests 3 molecules of oxygen, each containing one atom, and it is known that the molecule of oxygen contains two atoms.

The oxygen mixture mentioned in Chapter XXXIII contains manganese dioxide, MnO_2, in addition to potassium chlorate, and its behaviour in this reaction is of particular interest. At the end of the action the manganese dioxide is found to be unchanged though certain changes may have occurred during the reaction. Its presence has enabled the oxygen to come away from the potassium chlorate more easily and at a lower temperature. Substances which act in this way by influence without finally themselves decomposing are called **catalytic agents**, the influencing action itself being known as **catalysis**. In later chapters other cases will be noted.

Here are two more cases of substances which yield oxygen.

Mercuric oxide yields mercury and oxygen :

$$2HgO \rightarrow 2Hg + O_2$$
$$2 \times 216 = 2 \times 200 + 32,$$

and Red lead yields litharge and oxygen :

$$2Pb_3O_4 \rightarrow 6PbO + O_2,$$
$$2 \times 685 = 6 \times 223 + 32.$$

These are examples of reduction, and the burning of metallic magnesium may be taken as an example of the reverse process of oxidation.

Magnesium and oxygen produce magnesium oxide :

$$2Mg + O_2 \rightarrow 2MgO$$
$$2 \times 24 + 2 \times 16 = 2 \times 40.$$

Some metals tarnish in air not by oxidation but by combination with other substances present in the atmosphere, such as the sulphur of hydrogen sulphide. The necessity for frequent cleaning of silver articles is due to this, the reaction which produces the tarnish being expressed by the equation :

Silver reacts with hydrogen sulphide forming silver sulphide (tarnish) :

$$2Ag + H_2S \rightarrow Ag_2S + H_2.$$

free hydrogen

By means of equations accurately stated with the proper weights of the respective elements and molecules various useful calculations can be made. One or two common examples will make the mode of working clear.

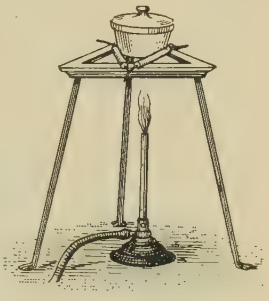


FIG. 306.

THE PROPORTION OF LIME IN LIMESTONE CAN BE DETERMINED BY HEATING POWDERED LIMESTONE IN A CRUCIBLE.

What weight of copper can be obtained by the reduction of one ton of ruby ore (an oxide of copper) by carbon ?

The equation is :

Ruby ore.		Carbon.		Carbon monoxide.		Copper.
Cu_2O	+	C	$\rightarrow$	CO	+	$2Cu$
142	+	12	=	28	+	126.

From this it is obvious that every 142 parts of ore yield 126 parts of metallic copper. Therefore one ton yields $1 \times \frac{126}{142}$ of a ton, or about 17·7 cwt. of copper.

What weight of pure limestone must be heated to yield one hundredweight of lime ?

Limestone yields		Lime and Carbon dioxide.		
$CaCO_3$	$\rightarrow$	CaO	+	CO_2
100	=	56	+	44.

One hundred parts of stone yield 56 parts of lime. Hence to obtain 1 cwt. of lime the quantity of stone required is $\frac{100}{56}$ or 1·8 cwt.

A large number of crystalline substances contain water; in such cases the water appears necessary for the formation of the crystals, and is known as **water of crystallisation.** Ordinary washing soda is one of these materials and as it slowly loses its water when exposed to air, the clear glassy crystals disappear, leaving a white powdery anhydrous (*i.e.* without water) residue.

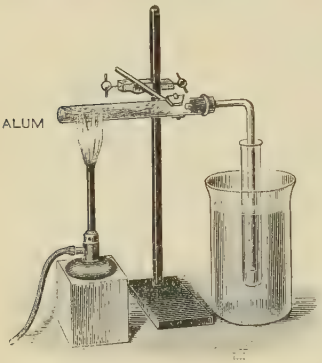


FIG. 307.
METHOD OF ESTIMATING THE PERCENTAGE OF WATER OF CRYSTALLISATION IN ALUM.

How much water is there in one lb. of washing soda?

The formula representing the composition of washing soda is $Na_2CO_3 10H_2O$ and the weights are $(106 + 180) = 286$. In 286 parts of soda there are 180 parts of water, therefore with 1 lb. of pure sodium carbonate there is $1 \times \frac{180}{286}$ of a lb. of water.

This worked out gives about 10 ounces; roughly about 62·5 per cent. of washing soda is water.

In later chapters other examples of calculation are given.

Experimental work with an accurate chemical balance yields results which agree with the proportions calculated from the respective formulae of various substances. For example, if 100 grams of finely powdered limestone are completely decomposed by heat, 56 grams of lime remain in the crucible, and these figures agree with the proportions indicated by the equation:

$$\underset{100}{CaCO_3} \rightarrow \underset{56}{CaO} + \underset{44}{CO_2}$$

The chemical balance has done enormous service to the progress of scientific knowledge, and in many cases has definitely caused scientists to turn from incorrect theories to others resting on surer foundations.

The overthrow of the famous **Phlogiston theory** is a classic example. A chemist named **Stahl,** professor at Halle in Germany,

suggested the theory that when a substance burns it parts with a material named phlogiston, and for many years the progress of chemical science was impeded by this view of combustion. As in many other cases, people were loth to give up some cherished theory and face the facts squarely, but eventually the evidence afforded by the balance could not be resisted. It was found that when a substance burned, or was oxidised, there was a *gain* in weight, and not a loss, as the phlogiston theory attempted to assert.

The credit of definitely destroying the phlogiston idea must be given to **Antoine Laurent Lavoisier**, a French chemist, born at Paris in the year 1743. He carefully heated tin, mercury, and other metals in air, and by accurate weighing proved that in all cases of oxidation the substance oxidised gained in weight, thus showing that instead of parting with the hypothetical material, phlogiston, they gained something from the air. Lavoisier not only showed that mercury heated in air oxidised and became heavier, but also that mercuric oxide yielded oxygen, a gas discovered by **Priestley**, an English Presbyterian minister, about the same time.

Both of these men led very eventful lives, Lavoisier eventually being guillotined because he had made an enemy of Marat, while Priestley's house near Birmingham was burned down, his goods destroyed, and his later days were spent in America.

Lavoisier made enemies because of his political activities; Priestley incurred trouble on account of theological disputes.

CHAPTER XXXVI

AMMONIA AND ITS COMPOUNDS

Ordinary household ammonia is a cloudy solution, used for removing grease from clothing, and has a characteristic smell due to ammonia gas dissolved in the solution. In former times a solution of ammonia was obtained by heating animal hoofs and horns in closed vessels, the vapours liberated dissolving in water forming a liquid called **spirits of hartshorn.** The decomposition of animal and vegetable matter commonly yields some ammonia as one of the products. The actual derivation of the name ammonia is rather obscure, but it may have had some connection with the Egyptian sun god, Ra-Ammon. Though compounds containing ammonia were known in ancient Egypt, the isolation of the gas itself was not accomplished until 1774, when Priestley succeeded in preparing it by heating a mixture of sal-ammoniac and lime. He collected the gas over mercury in a trough, but, had he employed water in the trough as an earlier investigator had done, he would not have succeeded in obtaining the gas, since it is extremely soluble in water. Priestley's method is that actually used nowadays in the laboratory, except that the ammonia, which is about half as heavy as air, is collected by displacing the air from an inverted glass cylinder, instead of using mercury in a trough.

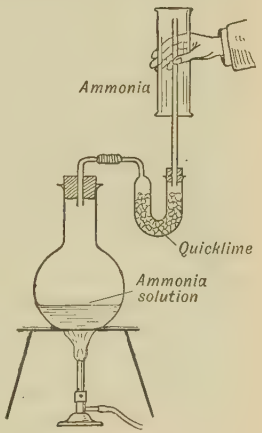


Fig. 308.
A method of preparing ammonia gas.

Sal-ammoniac, or ammonium chloride, is mixed with about twice its weight of dry lime and the mixture heated in a glass flask fitted with a delivery tube. Calcium chloride is formed in the flask, while ammonia and steam pass over :

$$\underset{\text{Ammonium chloride}}{2(NH_4)Cl} + CaO \rightarrow CaCl_2 + \underset{\text{Ammonia}}{2NH_3} + H_2O.$$

That ammonia consists of hydrogen combined with nitrogen can be shown by bringing these elements together and causing them to combine, forming **synthetic ammonia,** now produced commercially on a large scale.

The extreme solubility of ammonia in water is shown by the fact that at ordinary atmospheric pressure, one volume, say a cubic foot of water at 1° Centigrade, dissolves more than 1200 cubic feet of the gas. At ordinary room temperature, about 15° C., the quantity of ammonia dissolved is less, about 800 volumes, and this decrease of solubility of gases in water at a higher temperature is generally true. This is just the opposite of the case with solids, which dissolve more readily in hot than in cold water. Since gases are expelled from solution by heat, another mode of obtaining a sample of ammonia gas consists simply of boiling ammonia solution (Fig. 308).

In order to free the ammonia from the steam, the mixed gas is passed through a tall glass vessel containing dry calcium chloride which acts as a dehydrating agent, absorbing the steam. One or two jars of gas can be collected and simple experiments performed with it.

A lighted taper plunged into the gas goes out, showing that ammonia does not support combustion. Neither does the gas burn in air, though it will do so in undiluted oxygen, producing steam and nitrogen.

A little water placed in one of the jars and shaken dissolves the ammonia, forming a strongly alkaline solution commonly called ammonium hydroxide. Its alkaline or basic properties can be shown by a piece of red litmus paper turning blue when placed in the solution. The liquid sold commercially as strong ammonia has a specific gravity of 0·88, and contains about 35 per cent. of ammonia, the rest being water.

Large glass vessels in which ammonia or acids are sold are called *carboys*, and a carboy of ammonia contains roughly 90 lb. of solution.

ARTIFICIAL ICE AND REFRIGERATION

Compared with some other gases, ammonia is liquefied easily. Gases may be liquefied by a combination of increased pressure

FIG. 309.—BLOCKS OF ICE BEING EMPTIED FROM FREEZING TINS.
(By courtesy of Messrs. United Carlo Gatti, Stevenson & Slater, Ltd.)

and lowered temperature, and the greater the increase of pressure the less the fall of temperature need be. At ordinary atmospheric pressure, ammonia liquefies at -33° C., while at the higher temperature of melting ice, 0° C., a pressure equal to 4·2 times that of the atmosphere is required. This pressure is small compared with that employed in some chemical reactions, which require a pressure equal to more than 150 atmospheres.

Liquid ammonia is of great use commercially as a means of ice production or refrigeration. As the liquid ammonia evaporates, it absorbs heat from objects near it. Consequently the temperature of such objects falls, and if the object is water, it is converted to ice.

Reference has been made in Chapter XXI to the general principle of a refrigerating plant (Fig. 191), but a little more must be said here about the matter. Ammonia gas, which may be obtained by a reduction of pressure upon a solution of ammonia, is compressed in a series of pipes cooled by running water. By this means the heat resulting from compression is absorbed by the water, and the ammonia inside the chilled pipes becomes liquid. This liquid is then caused to evaporate in another system of pipes surrounded by a brine solution, in which are placed tanks containing water which ultimately becomes frozen to solid blocks of ice. The ammonia appearing at the end of the pipe system is again passed through the water-cooled first set of pipes and used again. Every gram of liquid ammonia in evaporating absorbs sufficient heat to freeze about 4 grams of water, and since every gram of water at 0° requires about 80 calories of heat merely to change it to ice, this is not a bad performance for one gram of liquid ammonia. It is not surprising that this substance has become almost universal as a means of producing artificial ice and cold storage on ships, etc., for the preservation of foodstuffs.

Under ordinary atmospheric pressure, and at a temperature of -78° C., ammonia is obtained as a white solid, but this must not be confused with what is called synthetic ammonia or with rock ammonia, the latter of which is really a compound properly called ammonium carbamate.

SYNTHETIC AMMONIA

Compounds of ammonia, since they contain nitrogen in a form suitable for soil improvement in agriculture, are of great importance. The necessity for obtaining atmospheric nitrogen in some suitable form is dealt with in Chapter XXXIX, where nitrates produced artificially are described, but here, some

description must be given of synthetically-produced ammonia and the sulphate derived from it.

Ammonia consists of nitrogen combined with hydrogen in the proportion represented by NH_3. When an electric spark is passed through a mixture of the two gases, a small proportion of ammonia is produced, but the reaction is reversible, that is, electric sparks decompose ammonia again. For these reasons

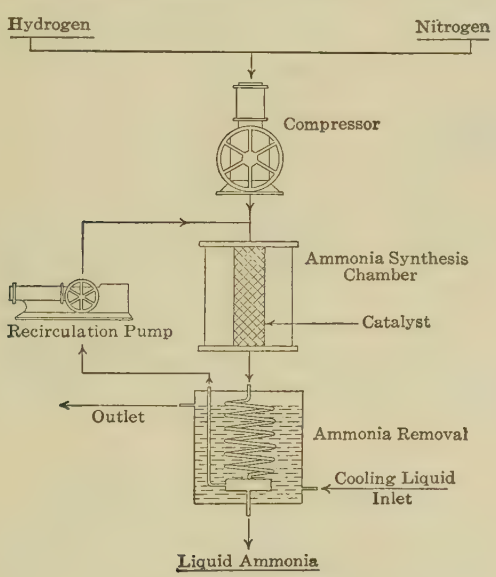


FIG. 310.

DIAGRAM REPRESENTING THE MANUFACTURE OF SYNTHETIC AMMONIA (HABER PROCESS).

some other method of building up ammonia is preferable, and in 1906 **Haber,** a German chemist, invented the process which now bears his name.

The principle of the process is, that under suitable conditions of pressure and temperature, and in the presence of a catalytic agent, such as *finely divided iron*, nitrogen and hydrogen combine to produce appreciable quantities of ammonia. The hydrogen can be obtained from the electrolysis of common salt, or one of the other commercial methods, while the nitrogen is

obtained from the evaporation of liquid air, and is thus indirectly derived from the atmosphere.

The gases, mixed in the correct proportions, are compressed under a pressure equal to about 180 times that of the atmosphere (*i.e.* 180 atmospheres or 2650 lb. per sq. inch), heated to about 600° C, and passed over the catalyst, which may be specially prepared iron or uranium carbide. Under these conditions, synthetic ammonia is produced. Ammonia gas or liquid is not in a form suitable for agricultural purposes, hence the ammonia produced is treated with sulphuric acid, so that the suitable compound called ammonium sulphate is obtained.

The production of synthetic ammonia and the resulting sulphate is an industry increasing by leaps and bounds. In the year 1925, 168,650 tons of ammonium sulphate were used in Great Britain, and in 1926, one British firm alone produced 73,000 tons of this useful compound. Just before the Great War, in 1913, for every ton of sulphate used in Britain, two tons of Chilean nitrate were employed, but now the conditions are reversed, five tons of sulphate being consumed against one ton of Chilean nitrate. All the ammonium sulphate is not obtained, however, by the synthetic method, large quantities being produced as a by-product of coal gas manufacture.

NEUTRALISATION AND SALTS

How does ammonia combine with sulphuric acid to produce ammonium sulphate? Ammonia gas turns red litmus blue, so does the solution in water. Both the gas and solution are alkaline. The term *alkali* is of Arabic origin, and is used to designate certain substances like sodium carbonate and ammonia solution which are capable of neutralising acids. Alkaline substances possess properties in many ways just the opposite of those of acids, and a carefully balanced mixture of an alkali with an acid is generally *neutral*, being neither acid nor alkaline.

A person who has swallowed an acid poison is given a dose of an alkaline substance such as sodium carbonate, or even plaster scraped from a wall.

In the laboratory it is quite simple to neutralise an acid by mixture with an alkaline substance. A little dilute sulphuric acid placed in a porcelain evaporating basin turns blue litmus red, yields hydrogen if zinc is placed in it, causes the evolution of carbon dioxide if a carbonate, such as washing soda, is immersed in it, and behaves generally as an acid (Fig. 311). Now, if a little ammonium hydroxide or solution of ammonia in water

$$NH_3 + H_2O \rightarrow (NH_4)OH$$

Ammonium hydroxide

is carefully added to the acid in the basin, a little at a time, and finally drop by drop, a mixture is obtained which turns litmus paper neither blue nor red. When this is the case the solution is neutral, and exhibits neither the properties of an acid nor those of an alkali. For example, zinc placed in it has no effect. The alkaline substance or **base** is said to neutralise the acid, and *vice versa*.

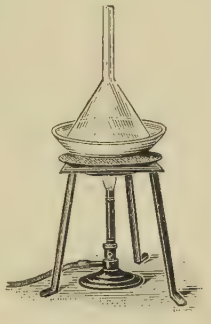


FIG. 311.

IF AN ACID SOLUTION IS NEUTRALISED BY A BASE AND THEN THE SOLUTION EVAPORATED, A SALT IS OBTAINED AS A RESIDUE.

Now, if this solution is evaporated nearly, but not quite, to dryness, and the residue allowed to cool, crystals of the salt called ammonium sulphate are obtained. When an acid, sulphuric or otherwise, is neutralised by a base, and the solution evaporated, a solid substance called a **salt** is obtained.

With sulphuric acid and ammonia solution the reaction is

$$H_2SO_4 + 2NH_4OH \rightarrow (NH_4)_2SO_4 + 2H_2O.$$

Ammonium sulphate

Note that the group or **radicle** NH_4 is called *ammonium*, and acts as if it were a metal like zinc, capable of replacing the hydrogen in an acid. But, unlike zinc, it is monovalent, one radicle being capable of replacing only one hydrogen atom. No actual free substance having a composition represented by NH_4 has been isolated. It is merely a group of atoms occurring in compounds, or as an **ion** in solutions (Chapter XXVIII).

If nitric acid is neutralised by an alkaline substance, say caustic soda, a salt called a **nitrate** is obtained.

$$HNO_3 + NaOH \rightarrow \underset{\text{Sodium nitrate}}{NaNO_3} + H_2O.$$

The group of atoms represented by NO_3 is an acid radicle, and has not been isolated as a separate substance. Similarly SO_4 represents the acid radicle of sulphuric acid found in sulphates. Thus a salt consists of a basic radicle or a metal combined with an acid radicle.

In some cases it is possible to obtain a salt from a solution that has not been completely neutralised. Consider the case of sulphuric acid mixed with caustic soda, the latter being in relatively small proportion, so that only one molecule instead of two reacts with one molecule of sulphuric acid.

$$NaOH + H_2SO_4 \rightarrow \underset{\text{Sodium bisulphate}}{NaHSO_4} + H_2O.$$

The salt produced contains hydrogen, and is called either sodium *bi*sulphate, or sodium hydrogen sulphate. When the solution is properly neutralised by caustic soda, the ordinary or *normal* sodium sulphate is produced :

$$2NaOH + H_2SO_4 \rightarrow \underset{\substack{\text{Normal}\\ \text{Sodium sulphate}}}{Na_2SO_4} + 2H_2O.$$

Thus, with an acid containing two replaceable atoms of hydrogen, ordinary salts and bisalts may be produced, and the acid is said to be **dibasic**. For this reason there are normal carbonates and bicarbonates derived from carbonic acid, and normal sulphites and bisulphites derived from sulphurous acid. Similarly, a **tribasic** acid, such as orthophosphoric, gives rise to three types of corresponding salts, a normal **phosphate** being the result when all of the three replaceable hydrogen atoms of the acid are replaced by a metal or basic radicles. The class of salts called phosphates are of considerable value, being found in bones, manures, and artificial fertilisers. Animal-waste products consist largely of calcium phosphate, and the fossilised excreta of reptiles, birds, etc., are found in some rocks in such quantity as

to be workable for the production of fertilisers. The Cambridge greensand contains coprolitic lumps of this sort.

Phosphorus, itself obtained by treating bone-ash or calcium phosphate with sulphuric acid, is a yellow, highly inflammable substance formerly used in making matches. A red non-poisonous kind of phosphorus is employed in medicine, and on account of a serious disease of the jaw attacking workers handling yellow phosphorus, since 1910 the use of yellow phosphorus for matches has been made illegal. Matches are now made of a nonpoisonous sulphide of phosphorus. Safety matches are composed of a sulphide of antimony, which is ignited by friction with red phosphorus and other substances placed on the box.

Whilst acids, such as sulphuric and phosphoric, are capable of yielding different kinds of salts, the *monobasic* acids, hydrochloric and nitric, can only produce one sort of chloride and nitrate respectively, because these acids have only one replaceable hydrogen atom in a molecule.

It must be noted that the term salt is applied to a substance which contains a combination of an acid radicle with a basic radicle, whether it has been prepared in the laboratory, occurs as a product of a commercial process, or occurs naturally as a mineral substance. Of course, there are a great many substances that are not salts: sugar, paraffin, elements like sulphur, and so on. A characteristic feature of salts is that their solutions in water conduct a current of electricity and are said to be **electrolytes**. On the other hand, solutions of most substances which are not salts do not act in this way because they are not ionised, or split, into electrically charged ions as solutions of salts are.

When some ammonium sulphate is placed in water, the molecules of the dissolved substance are *dissociated*, or split up into two contrasting kinds of electrified ions, the positive ions NH_4 and the negative ions SO_4. Though neither NH_4 nor SO_4 has been isolated as a chemical compound in the ordinary way, yet in water solution these electrified bodies certainly exist, and it is because of this ionic dissociation that electricity is conducted through the solution in the manner described in Chapter XXVIII. Most acids, such as hydrochloric, and also bases, for example caustic soda, also exhibit ionisation and act as electrolytes. In

some cases of electrolysis, for example, hydrochloric acid, the dissociated parts are ions of hydrogen and chlorine, but it must be noted these ions are electrified, but when the gases themselves are collected in jars in the ordinary way they are not electrified.

VOLUMETRIC DETERMINATIONS

In the laboratory it is often necessary to determine the strength of solutions, particularly those of acids and alkalies. The usual method consists of carefully adding a **standard solution** to the solution the strength of which is to be determined. Any

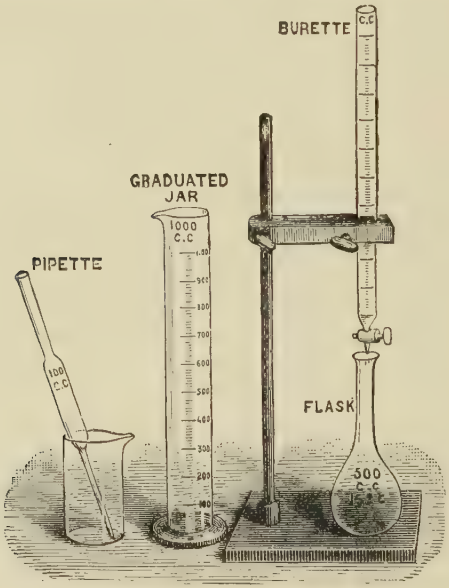


FIG. 312.—VESSELS EMPLOYED IN VOLUMETRIC ANALYSIS.
THE STANDARD SOLUTION IN THE BURETTE IS TITRATED WITH THE SOLUTION IN THE FLASK.

standard solution is made by dissolving a definite weight of compound in a definite volume of water. For example, a standard solution of sulphuric acid contains 4·9 grams of acid made up with distilled water to a volume of 1000 c.c. exactly.

Such a solution can be used to find the strength of any alkaline solution, say one of caustic soda. The acid is placed in a long graduated tube called a **burette**, and a definite volume, say 25 c.c. of the caustic soda solution, is placed in a conical flask. By means of a tap at the lower end of the burette the acid is added carefully, a little at a time, to the caustic soda. Some litmus solution is placed in the caustic soda as an **indicator**. The solution remains blue until just a drop too much acid has been added, when the solution turns red. The action is then stopped, and by noting the amount of acid solution used, the amount of caustic soda in the 25 c.c. can be found by calculation. The mode of calculation cannot be dealt with in detail here, but this brief outline of the process, known as **titration**, may serve to show the importance of standard solutions in practical chemistry.

Returning to the ammonium compounds, another salt that must be noted is the chloride, commonly called **sal-ammoniac**. This results from the neutralisation of hydrochloric acid by ammonia solution :

$$HCl + (NH_4)OH \rightarrow (NH_4)Cl + H_2O.$$

In the process of manufacture, ammonia gas is passed into dilute hydrochloric acid solution and the sal-ammoniac settles out as a white solid. The crude material is then purified by **sublimation**; the product is heated in a large iron vessel, the salt vaporises, and pure ammonium chloride settles as a sublimate on the upper part of the vessel. This ammonium compound is used chiefly in electric cells and batteries of the Léclanche type, in the process of galvanising iron, and for soldering, because it protects the metals being joined from oxidising under the influence of heat.

CHARACTERISTICS OF CRYSTALS

If a few drops of saturated ammonium chloride solution are placed upon a slip of glass and viewed through a microscope, arborescent or fern-like growths of sal-ammoniac crystals can be watched in the process of formation.

Ammonium sulphate also forms crystals. Some substances assume these definite crystal shapes as they are deposited from

solutions or result from the cooling of either a heated molten mass or a heated vapour. Washing soda crystallises from aqueous solution, iron crystallises from the molten state, and the mineral tinstone passes from vapour to solid crystal. Of course a large number of substances never form crystals—they are always amorphous.

The same crystallised substance usually assumes the same shape or shapes, hence a knowledge of crystallography is of use to the **prospector,** who must distinguish between certain minerals. The characteristic crystal form of common salt is the cube, that of alum is the octahedron, and the mineral pyrites, a sulphide of iron, occurs either as a cube or in a shape known as the

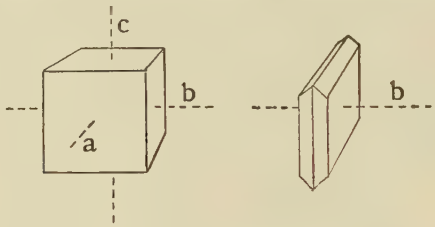


FIG. 313.—A CUBIC CRYSTAL OF SALT AND A CRYSTAL OF GYPSUM.

THE CUBE HAS MANY AXES OF SYMMETRY, INCLUDING *a*, *b*, AND *c*, BUT THE GYPSUM HAS ONLY ONE AXIS OF SYMMETRY, VIZ., *b*.

pyritohedron. A substance like sulphur which crystallises in several different forms according to conditions of temperature and pressure is said to be **polymorphous.**

A crystal is a solid bounded by a number of surfaces or **faces.** These faces are nearly always flat, but in a few cases, diamond, for example, they are curved. When all of the faces are alike and interchangeable, as in a cube, the crystal has a high degree of **symmetry** (Fig. 313). In such cases it is possible to find several **axes,** or lines passing through the crystal, about which it can be rotated, so that similar faces come immediately in front of the observer several times in a rotation through 360°. When a cube is rotated about the axis *c*, four exactly similar faces come into position during one complete rotation. Similarly the axes *a* and *b* are also of fourfold symmetry. On the other hand, in a crystal of gypsum,

or calcium sulphate, there is only one axis (*b*) about which it can be rotated so that similar faces come into position more than once, and then only twice in a rotation. The axis is one of twofold symmetry only. The symmetry of a gypsum crystal is low. There are other crystals of still lower symmetry, copper sulphate for example (Fig. 321), where no axis can be found; there is merely a *centre* of symmetry within the crystal. Planes of symmetry also pass through most crystals dividing them into similar symmetrical portions. The higher the symmetry the greater the number of planes.

Any crystal can be referred to one of six systems according to its degree of symmetry. These systems in order of decreasing

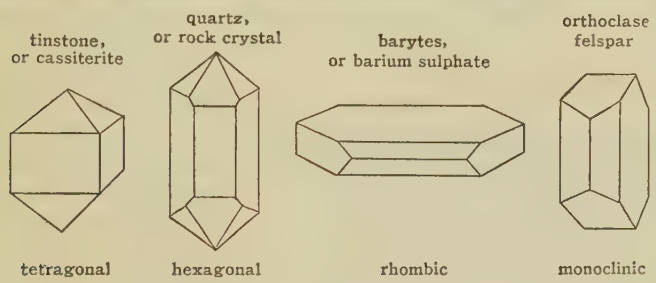


FIG. 314.—TYPES OF CRYSTALS
BELONGING TO DIFFERENT SYSTEMS OF SYMMETRY.

symmetry are—cubic, hexagonal, tetragonal, rhombic, monoclinic, and triclinic. Useful chemicals and minerals crystallising in the cubic system are rock salt, fluorspar, iron pyrites, alum, and lead ore. Calcite and quartz are examples of hexagonal minerals, tin ore is tetragonal, barium sulphate, a mineral used in paint manufacture, is rhombic, orthoclase felspar, which alters to the valuable clay kaolin, is monoclinic, and the other felspars are triclinic.

A substance may have internal crystalline structure and yet show very poor external faces or perhaps none at all. Crystal faces when present are *the outward expression of internal molecular structure*. Much knowledge concerning internal crystal structure has been obtained by **Sir William Bragg** and his son, **Prof. W. L. Bragg,** who have made experimental observations on the

behaviour of crystals with regard to X-rays incident upon them. Following the earlier work of **Dr. Laue** of Zurich, these investigators have shown that the ultimate atoms of the crystalline substance are arranged symmetrically in patterns. X-rays, being ether vibrations of extremely small wave-lengths, are capable of penetrating the spaces between the atoms of a substance; consequently they are used as a probe to investigate the relative positions of the atoms and gaps in the crystal.

One of the simplest examples is afforded by a crystal of silver or aluminium. These metals crystallise in cubes, and the atoms of silver or aluminium are symmetrically placed, forming a **lattice structure** with an atom at each corner and in the middle of each face of the cube. This particular pattern is known as a *face-centred cubic lattice*. When the metals iron and sodium crystallise, they do so in cubes, but in these cases the atoms are arranged with one at the centre of the cube, and none in the centres of the faces. Such a pattern is called a *cube-centred cubic lattice*.

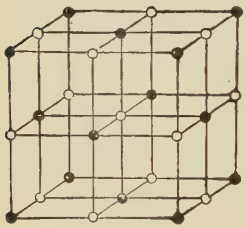


FIG. 315.—THE LATTICE PATTERN

FORMED BY ATOMS OF SODIUM AND CHLORINE IN A CRYSTAL OF SALT.

Sodium atoms ○
Chlorine atoms ●

In the case of common salt, a compound substance, a simple cubic lattice is made with atoms of sodium and chlorine at alternate corners of minute units, and in the combination of these units, to build up a definite crystal, an atom of sodium is situated at the centre (Fig. 315).

It appears that the sodium and chlorine atoms are held in place by electrical forces of attraction, the sodium being positive, the chlorine negative.

Crystals of many compounds are composed of atoms arranged in a much more complicated way, but the simple cases quoted above are sufficient to show the kind of result obtained by probing the structure of crystals by means of X-rays.

CHAPTER XXXVII

SULPHUR AND SULPHURIC ACID

THOUGH volcanoes are often associated with trouble and disaster, there are some advantages to be placed to the credit of volcanic action. For example, **boric acid** is obtained from fumes escaping from vents in some volcanic districts and is sold as an antiseptic known as boracic powder and in ointment. But the most useful material obtained is the pale yellow solid called **sulphur,** often popularly termed brimstone. The world's annual consumption of this substance is more than 2,500,000 tons, and about ten per cent. of this is obtained from the island of Sicily which contains the giant volcano, Etna.

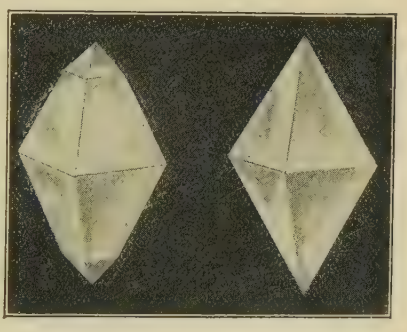


FIG. 316.—CRYSTALS OF RHOMBIC SULPHUR.

The sulphur occurs as an incrustation covering rocks and is usually crystalline, assuming the form of *rhombic* pyramids (Fig. 316). This deposit is formed as the result of chemical reaction between volcanic vapours, particularly sulphur dioxide and hydrogen sulphide :

$$\underset{\text{Sulphur dioxide}}{SO_2} + \underset{\text{Hydrogen sulphide}}{H_2S} \rightarrow \underset{\text{Water}}{2H_2O} + \underset{\text{Sulphur}}{3S}.$$

Since the sulphur is obtained as an element it is described as *native*, just as metallic copper found in nature is known as native

copper. The crude sulphur is more or less mixed with earthy matter and is purified simply by burning some of it ; the heat melts the greater part of the remainder, which is run into moulds, from which round sticks of roll sulphur are obtained. Further purification is obtained by passing sulphur vapour into brick chambers, where it condenses to a fine powder known as flowers of sulphur, a substance used medicinally.

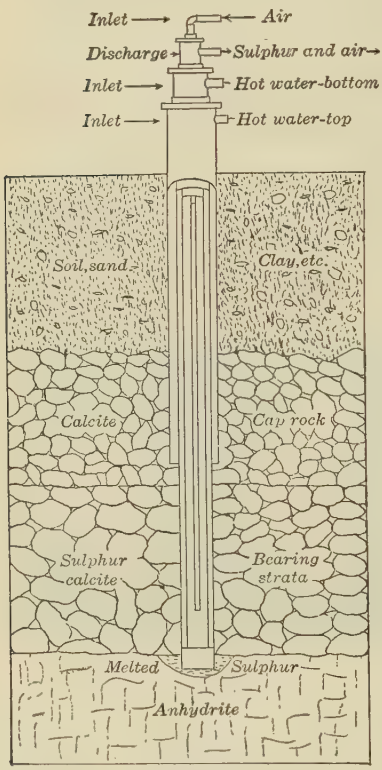


FIG. 317.
DIAGRAM SHOWING THE ARRANGEMENT OF PIPES IN THE FRASCH PROCESS.

Though in Sicily and Japan sulphur is of volcanic origin, this is not always the case. America produces more than 2,000,000 tons yearly, and obtains its supplies from Louisiana and Texas, where the sulphur is found as definite beds of rock some distance below the surface of the ground. Such beds are probably due to the subsequent reduction or chemical alteration of material which was originally deposited as sulphates, such as gypsum.

The sulphur is obtained by the **Frasch process,** in which a series of pipes, one inside another, is placed in deep borings (Fig. 317). Hot water is forced down the outermost pipes with the result that melted sulphur collects in the middle pipe, and is then forced to the surface of the ground by means of compressed air passed into an innermost pipe. A single ' sulphur well ' of this type may yield as much as 500 tons of pure sulphur in a day.

A certain amount of sulphur is also obtained from the purifica-

tion of coal gas employed for lighting purposes, and from the alkali-waste resulting from the manufacture of sodium carbonate.

In combination with metals, sulphur occurs as mineral **sulphides** in veins traversing limestones and other rocks, and if oxygen entered into combination as well, mineral sulphates have been formed, such as alabaster and barytes, each of which has important uses (Chapter XLI).

The rhombic crystals of sulphur melt at a temperature of 112·8° forming a pale yellow liquid which, if allowed to cool slowly, produces long needle-like *monoclinic* crystals, so called because they belong to another system of crystal shapes bearing that name. At ordinary temperatures the monoclinic sulphur tends to change to the rhombic form, but above 96° the reverse is the case, rhombic sulphur then being unstable and tends to assume monoclinic shapes. The melting points are also different, monoclinic sulphur becoming liquid at 119·25°. In addition to the long crystals of mo oclinic sulphur there are at least two other flat tabular types of crystallised sulphur, both of these also being monoclinic in symmetry (Fig. 318). Sometimes rhombic sulphur is simply represented by S_I, the monoclinic kinds being symbolised by S_{II}, S_{III} and S_{IV}, but it must be clearly understood that in this case the figures do not represent numbers of atoms. A substance such as sulphur which occurs in several distinct crystalline forms is said to be *polymorphous* (*i.e.* many forms).

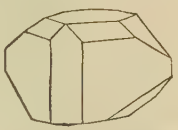


FIG. 318.—ONE FORM OF MONOCLINIC SULPHUR.

The various forms of sulphur, including the amorphous kind, are also known as **allotropic modifications**; similarly, carbon exhibits allotropy, since it occurs in various forms, amorphous (charcoal) and crystallised (diamond).

The properties of sulphur which make it of practical value are, however, mainly of a chemical nature. It burns readily, forming the irritating gas, **sulphur dioxide**, and on account of its inflammable nature, sulphur is one of the constituents of gunpowder, fireworks, and some matches. A combination of sulphur with rubber is called **vulcanite**, and is used for many purposes, including the manufacture of fountain pens, mouthpieces for tobacco pipes,

and plates to support artificial teeth. A form of vulcanite used for wireless apparatus is known as ebonite.

Sulphur belongs to a family of elements including oxygen and the rarer substances **selenium** and **tellurium** ; of these selenium, a red powder found in the flues of the pyrites burners used in sulphuric acid manufacture, is of particular interest on account of its behaviour towards light and electricity. As the intensity of light falling upon its varies, its power of conducting an electric current varies correspondingly. On account of this remarkable feature a selenium **light valve** is employed on automatic luminous buoys at sea. When daylight fails the selenium material becomes a better conductor of electricity and apparatus is set working which lights the lamp.

SULPHUR DIOXIDE

When sulphur burns in air or in oxygen a gaseous oxide of sulphur, SO_2, is produced. Since the gas possesses good properties as a disinfectant, it is employed for the fumigation of rooms, etc., after cases of measles or other infectious diseases. The sulphur dioxide fumes have a most disagreeable odour and are soluble in water, forming sulphurous acid.

This acid, or sulphur dioxide in the presence of water, is capable of bleaching coloured material, that is, it removes the colour, a fact which can be quite easily demonstrated by holding a piece of *wet* coloured fabric in a jar of the gas. This action is due to the liberation of hydrogen when sulphur dioxide is brought into contact with water, thus, $SO_2 + 2H_2O \rightarrow H_2SO_4 + H_2$. The hydrogen is a reducing agent (Chapter XXXIV), and reduces the colouring matter, forming new compounds. This method of bleaching is suitable in the case of delicate materials, such as silk or straw, which might be injured by certain other bleaching agents, such as chlorine.

For demonstrative purposes, sulphur dioxide is prepared by heating metallic copper with sulphuric acid (Fig. 319). The copper replaces hydrogen in the acid, but not all of it, and in this way the reaction differs from that which takes place when zinc or iron is placed in sulphuric acid.

Copper sulphate and water are produced as well as sulphur dioxide.

The gas is easily liquefied at the relatively high temperature of $-8°$ C., and though the evaporation of liquid ammonia is now

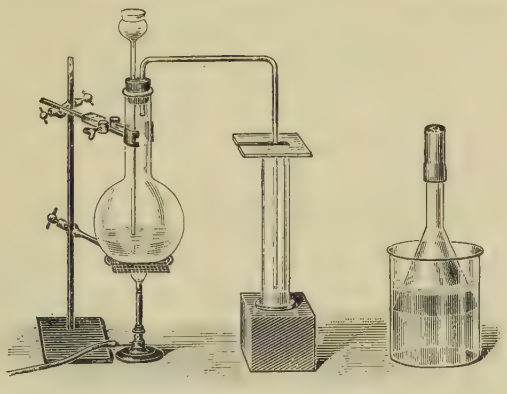


FIG. 319.—PREPARATION OF SULPHUR DIOXIDE.
IF THE FUNNEL, SHOWN ON THE RIGHT, IS ATTACHED TO THE DELIVERY TUBE AND THE GAS PASSED INTO WATER AN ACID SOLUTION IS OBTAINED.

generally employed for the production of commercial ice, liquid sulphur dioxide can also be used for this purpose. In contact with the water-containers the liquid evaporates, and in doing so extracts much heat from the water, which freezes in consequence.

THE MANUFACTURE OF SULPHURIC ACID

A solution of sulphur dioxide in water, or sulphurous acid exposed to the air, slowly absorbs oxygen, becoming sulphuric acid :

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4.$$

But this action is slow and quite unsuitable as a means of obtaining the large supplies of sulphuric acid required for various industrial purposes mentioned below. The manufacture of sulphuric acid is accomplished by a *synthetic* method, that is, the various necessary elements are brought together under conditions which induce them to combine. The necessary materials include steam, which supplies hydrogen ; sulphur dioxide ; air

which supplies oxygen ; and an oxide of nitrogen, the action of which is catalytic and causes the sulphurous acid to be rapidly oxidised to sulphuric acid. The actual reactions which bring about the desired result are by no means simple, and an adequate discussion of them is scarcely possible here ; nevertheless, some idea concerning the mode of production can be obtained by reference to the chief parts of a large acid manufacturing works. Such works consist of a collection of furnaces, towers, and large leaden chambers (Fig. 320).

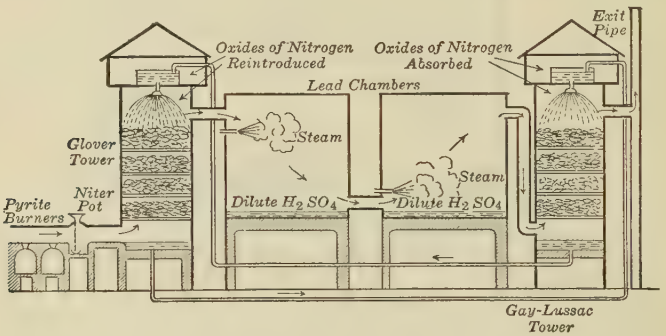


FIG. 320.

DIAGRAM REPRESENTING THE CHAMBER PROCESS FOR THE MANUFACTURE OF SULPHURIC ACID.

First the sulphur dioxide is produced by burning the mineral called **pyrites,** a natural sulphide of iron. The gas thus obtained is passed along pipes where it mixes with air, the mixture being then passed upwards through a tower containing broken tiles or flints. This is known as the **Glover Tower,** and is the place where the oxide of nitrogen, prepared from nitric acid, is added to the gaseous mixture. The gases then pass into the first of a series of very large chambers completely lined with lead, which has no action upon the acid produced. In these chambers steam is added and the gases become thoroughly mixed and interact with the formation of sulphuric acid. Excess of air and the oxide of nitrogen not used in the chambers pass into another ' **Gay Lussac** ' tower containing broken coke or tiles. Strong sulphuric acid trickling down through this tower absorbs

the oxide of nitrogen, and the liquid is fed back to the Glover Tower so that the oxide may not be wasted. The circulation of gases through the various compartments is caused by the draught due to a tall chimney.

The acid which collects on the floors of the leaden chambers is not concentrated and has a specific gravity if 1·5 to 1·6. By evaporation in leaden vessels the density is increased and brought to 1·83, the correct specific gravity of commercial **oil of vitriol**, as the sulphuric acid is commonly termed. Quite pure concentrated acid has at ordinary temperatures (15° C.) a specific gravity of 1·85. Another method of sulphuric acid manufacture is known as the **contact process**. This process is based upon catalysis; the sulphur dioxide and oxygen combine in the presence of ferric oxide or finely divided platinum to form sulphur trioxide which with steam gives sulphuric acid.

The uses of sulphuric acid are very numerous, in fact it plays a part in most chemical industries, such as the production of sodium sulphate and sodium carbonate, the manufacture of superphosphate, a substance used extensively as a fertiliser in agriculture, the refining of oil, and the manufacture of dyes obtained from coal tar. The acid combines eagerly with water, hence it is a good **dehydrating agent** or substance employed for drying gases and other materials and for removing water from compounds. On account of this latter property it is used in the preparation of explosives, such as guncotton and nitroglycerine (Chapter XXXIX).

Its readiness to combine with water is shown by the considerable rise in temperature which occurs in the mixture when it is added to water in the preparation of dilute acid for use in accumulators, etc. *Water should never be added to the concentrated acid*, but the acid should always be added to water, a little at a time, and the mixture stirred with a glass rod. Wood, sugar, and paper, which may be regarded as containing carbon and water, are converted to black carbon by the absorption of water when strong sulphuric acid comes in contact with them. Even when dilute the substance exhibits a strongly corrosive action upon metals, fabrics, and other materials, hence the necessity of providing accumulators with strong glass or celluloid cases.

Sheet iron is cleaned by dilute sulphuric acid before being tinned or galvanised. Very large quantities of the acid are employed for educational purposes in colleges and schools, and for research purposes in laboratories.

BLUE AND GREEN VITRIOLS

The hydrogen of sulphuric acid may be replaced by a metal with the production of a sulphate, as when zinc takes the place of the hydrogen in the laboratory method of preparing that gas. Instead of zinc, magnesium, or iron could be employed, in which case magnesium sulphate or iron sulphate is formed.

Thus, with magnesium ;

$$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2.$$

Crystallised magnesium sulphate containing water, $MgSO_4 \cdot 7H_2O$, is known as **Epsom salts**, and is used medicinally.

These sulphates and some others are of considerable importance and are manufactured on a large scale. Zinc sulphate or white vitriol is used in cotton printing, while ferrous sulphate is employed for dyeing and for the manufacture of writing ink. A substance called tannic acid is found in nut galls, and this combined with ferrous sulphate forms a compound which, though almost colourless itself, oxidises in air forming a black substance. Dark colouring matter is added to the ink so that it is visible immediately it is written, though when dry the colour is due to the formation of a black substance by oxidation of the ferrous constituent. These ferr*ous* substances have a tendency to take up more oxygen and become ferr*ic* compounds in which the proportion of iron is less. The formulae of the two sulphates

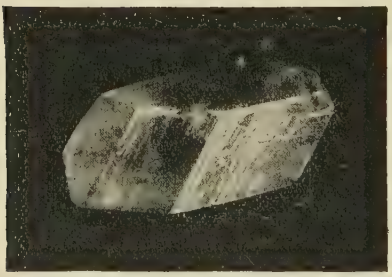


FIG. 321.—A CRYSTAL OF COPPER SULPHATE.

of iron illustrate these compositions. That of ferrous sulphate is $FeSO_4$, while that of ferric sulphate is $Fe_2(SO_4)_3$. The permanence of ink on paper is thus due to the formation of a ferric compound.

The crystallised form of ferrous sulphate, known as **green vitriol** and as copperas, has a composition represented by $FeSO_4\,7H_2O$. This is another example of a substance containing water of crystallisation.

Copper sulphate or **blue vitriol** is a dark blue crystalline material containing rather less water of crystallisation, its

FIG. 322.—A POTATO SPRAYER.
SPRAYING BORDEAUX MIXTURE, CONSISTING OF COPPER SULPHATE AND SLAKED LIME, ON POTATO PLANTS.
(By courtesy of the Four Oaks Spraying Machine Co.)

formula being $CuSO_4\,5H_2O$. On being heated the substance gives up the water, leaving a whitish residue of anhydrous sulphate $CuSO_4$, which immediately turns blue again on the addition of water. Though it may be prepared in the laboratory by dissolving copper oxide in sulphuric acid, commercially it is manufactured by heating copper with sulphur in the presence of air. The uses of copper sulphate include the deposit of copper from a solution of the substance in the process of electro-plating (see Section II, Chapter XXVIII) and as a mordant in dyeing.

The name mordant, derived from the Latin word meaning to bite, is applied to certain substances which enable fabrics to take or 'bite' the colouring matter. In agriculture and horticulture copper sulphate is used in a spray or as a dust for the prevention of the formation of fungi on seeds, foliage, etc. (Fig. 322).

ALUMS

There is a very useful and interesting class of crystallised double sulphates known as **alums**. The substance simply called alum is a double sulphate of potassium and aluminium represented by the formula $K_2SO_4 \cdot Al_2(SO_4)_3\,24H_2O$. An alternative name is 'Crystallised potassium-aluminium sulphate.' On being heated, the crystals, which are octohedral in form (Fig. 323), give up the water, leaving a white porous mass known as burnt alum.

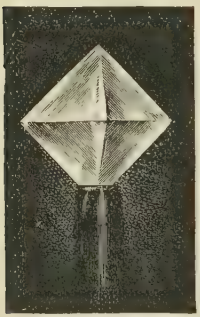


FIG. 323.—A CRYSTAL OF ALUM.
THE FORM IS THAT OF THE OCTAHEDRON.

A basic potash alum occurring naturally is called alum stone, and considerable quantities of alum are obtained from alum shale by the process of heating, and then treatment of the residue with potassium sulphate to supply the necessary potash. Ordinary alum is employed as a mordant and is an astringent.

There are several other alums; thus, if iron takes the place of aluminium, iron alum, with a composition represented by $K_2SO_4 \cdot Fe_2(SO_4)_3\,24H_2O$, is formed. Similarly, chrome alum is formed when chromium takes the place of the aluminium. All these alums crystallise in similar octahedral forms, thus affording an example of an **isomorphous series** of compounds. Substances are said to be isomorphous when they have similar but not identical compositions and crystallise in the same shapes.

OTHER SULPHUR COMPOUNDS

As mentioned above, there is another useful class of compounds containing sulphur and known as sulphides, which are different

from sulphates in containing no oxygen ; they consist of metal and sulphur only. Thus ferrous sulphate has the formula $FeSO_4$, but ferrous sulphide is represented by FeS. Many metallic sulphides, particularly those of lead, zinc, and mercury, are the principal ores of the respective metals and are described in a later chapter.

Dilute acids act upon most sulphides with the production of **hydrogen sulphide,** a gas formed in bad eggs. In the laboratory this gas is prepared by the action of hydrochloric acid upon iron sulphide.

$$\underset{\text{Ferrous sulphide}}{FeS} + \underset{\text{Hydrochloric acid}}{2HCl} \rightarrow \underset{\text{Ferrous chloride}}{FeCl_2} + \underset{\text{Hydrogen sulphide}}{H_2S}.$$

Since the gas is soluble in cold water it must be collected either over hot water or by displacement of air.

In analytical work hydrogen sulphide is employed for the detection of copper, tin, lead, bismuth, and certain other metals in solutions. By passing the gas through the solution, a metallic sulphide is deposited, thus :

$$\underset{\text{Copper sulphate}}{CuSO_4} + H_2S \rightarrow H_2SO_4 + \underset{\text{Copper sulphide}}{CuS}.$$

By the burning of hydrogen sulphide, water and sulphur dioxide are produced :

$$2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O.$$

When hydrogen sulphide is passed through a porcelain tube heated to a very high temperature the gas *dissociates*, yielding hydrogen and sulphur, but at a lower temperature, below 400°, free sulphur and hydrogen recombine to form hydrogen sulphide again. This is an example of a **reversible reaction** and is expressed by the equation :

$$2H_2S \rightleftarrows 2H_2 + S_2.$$

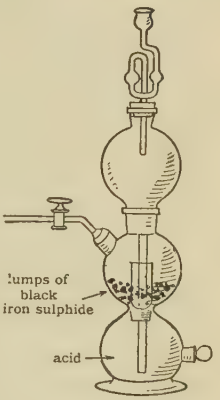


FIG. 324.—A KIPP'S APPARATUS FOR THE GENERATION OF SULPHURETTED HYDROGEN GAS AS REQUIRED.

As a contrast to this type of chemical change is the irreversible or complete reaction, an example of which is the action between zinc and sulphuric acid. In such cases the products once formed do not attempt to recombine with the formation of the original substances.

CHAPTER XXXVIII

COMMON SALT AND RELATED SUBSTANCES

The soft grey metals potassium and sodium, which liberate hydrogen from water (Chapter XXXIV), were discovered in 1807 by Sir Humphry Davy, who isolated them by passing an electric current through their respective hydroxides. At the present time electrolysis is employed for the production of both these metals as well as some others.

Though the discovery of the metal is relatively recent, compounds containing sodium have been known and used for many centuries; for example, **natron**, a natural mineral carbonate of soda, occurs in Egypt, where it was employed for the manufacture of glass long before the Christian era. Similar deposits of **trona** occur in California and in some desert regions, but supplies obtained from these mineral carbonates are quite inadequate; in fact, so far back as the times of the French Revolution, the quantities of sodium carbonate were insufficient for chemical industries. About that time the French chemist, **Leblanc**, invented the first process by which the carbonate was produced, when common salt was used as a starting point.

Of the numerous compounds of sodium the carbonates are perhaps the most useful, not only in commercial processes, but also in the household, as the names baking soda and washing soda indicate. Salt and borax are two other compounds found in practically every home, while caustic soda is employed in the manufacture of soap and various chemicals. Sodium nitrate or Chile saltpetre is used for making nitric acid and gunpowder.

SALT AND CHLORINE

Ordinary white salt or sodium chloride is obtained by the purification of the brownish impure mineral **rock salt** found in

Cheshire and elsewhere as a stratified deposit which has resulted from the drying up of ancient salt lakes. Seams of rock salt are found mostly in rocks of Triassic age, that is, they were formed some time after the coal measures, but long before the chalk. Conditions in salt lakes are not very suitable for animal life, consequently the rocks associated with salt contain very few fossils. The mineral salt occurs usually in amorphous or non-crystalline form, though sometimes clear glassy crystals occur, and these assume the shape of the cube (Fig. 325). Commonly, iron oxides give brown, yellow, or even red tints to the usual

FIG. 325.—CRYSTALS OF COMMON SALT.

amorphous form of rock salt. Since the mineral salt is very soluble in water its purification is merely a matter of solution and then recrystallisation. In some cases the actual process of mining consists simply of sending water into the salt-bearing beds, pumping out the resulting brine solution, and allowing the salt to crystallise as the water evaporates.

Some regions not favoured with rock salt obtain supplies by the evaporation of sea water, though salt obtained in this way contains many impurities (Fig. 326).

Deposits of rock salt are often of great thickness, indicating a long period of evaporation in bygone times. The salt beds of Wielieza in Galicia, where mining has been carried on for hundreds of years, are more than 1200 feet thick, and yield nearly 60,000 tons of salt in a year.

The uses of salt are varied. For table purposes the effect of traces of magnesium and calcium chlorides which cause the substance to absorb moisture must be counteracted, and this is achieved by the addition of a little baking soda, hence the brands of special table salt that are on the market.

FIG. 326.—HARVESTING SALT FROM THE CASPIAN SEA.

Salt not improved in this way is employed on a large scale for the preservation of fish and other articles of diet, in the manufacture of soap, and for the preparation of many useful compounds of sodium, including salt cake, baking soda, and washing soda. A mixture of salt and ice forms a freezing mixture having

a temperature of 0° Fahrenheit, and can be used for making ice creams, etc.

Appearances of most compounds are very deceptive, and there is nothing in the appearance of salt to suggest that it is composed of the metal sodium and the poisonous greenish yellow gas, **chlorine**, discovered by **Scheele** in 1774, but believed by him to be a compound. It was shown to be an element by Davy in 1810.

That salt contains chlorine can be shown easily by passing an electric current through a solution of salt. Carbon electrodes must be used for this electrolysis, since chlorine reacts with platinum, forming platinic chloride. The chlorine liberated can be collected in a suitable tube placed over the electrode connected to the positive terminal of the battery. Particles of sodium are not collected at the other electrode, however, since the metal immediately reacts with the water of the solution, forming caustic soda, while hydrogen is set free.

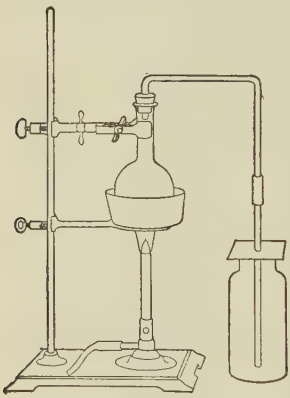


Fig. 327.
The preparation of chlorine in the laboratory.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2.$$

The final products of the electrolysis are the same as if strong hydrochloric acid had been placed in the apparatus instead of brine.

Without the aid of an electric current chlorine can be obtained from salt by mixing it with some manganese dioxide and concentrated sulphuric acid, the mixture being heated in a flask fitted with a delivery tube (Fig. 327).

Sulphates of manganese and sodium are formed besides water and free chlorine :

$$\underset{\text{Salt}}{2NaCl} + MnO_2 + 2H_2SO_4 \rightarrow \underset{\substack{\text{Sod.}\\\text{sulphate}}}{Na_2SO_4} + \underset{\substack{\text{Manganese}\\\text{sulphate}}}{MnSO_4} + 2H_2O + Cl_2.$$

Instead of using salt, hydrochloric acid, which is really hydrogen chloride, may be mixed with the powerful oxidising agent

manganese dioxide and heated in a flask, when the hydrogen is oxidised to water and part of the chlorine is obtained as gas.

$$4HCl + MnO_2 \rightarrow 2H_2O + MnCl_2 + Cl_2.$$

This equation represents the final result achieved, but it is believed that at some time during the reaction higher chlorides of manganese are formed but subsequently decompose.

As chlorine is soluble in water, it is collected by displacement of air, the lighter air being pushed upwards. Care must be exercised to avoid inhaling the gas as it is very injurious, and for this reason it was used as poison gas on an extensive scale in the Great War.

Though such a use is to be deplored, in other ways chlorine is beneficial. In one method of gold extraction from auriferous rocks, chlorine is employed, and is taken as a liquid in strong steel cylinders lined with lead to the place where it is to be used.

A piece of coloured fabric moistened and then plunged into a jar of the gas is bleached or loses its colour, because chlorine *in the presence of water* forms the bleaching agent called **hypochlorous acid** (HOCl). This acid tends to form hydrochloric acid, HCl, and liberate oxygen, the bleaching action being due to the oxidation of the colouring matter with the formation of new colourless or less coloured substances.

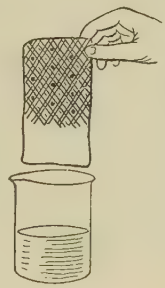


Fig. 328.—Bleaching Fabric by means of Hypochlorous Acid.

The decomposition of hypochlorous acid is represented by the equation

$$2HOCl \rightarrow 2HCl + O_2.$$

Just as there are salts called chlorides derived from hydrochloric acid, so there are **hypochlorites** derived from hypochlorous acid, and these substances also possess bleaching properties. A solution containing sodium hypochlorite is now sold extensively for cleansing and for disinfecting purposes, since oxidation of harmful organic matter alters its composition, rendering it harmless (compare Permanganate, Chapter XXXIII). The bleaching industry is a very important one, many fabrics, such as cotton and linen, having to be bleached before they are fit for

use, and a most suitable form of hypochlorite employed for this purpose is known as **bleaching powder.** This is the calcium salt prepared by passing chlorine over lime agitated in rotating cylinders. The chlorine and lime combine to form bleaching powder, also known as chloride of lime.

$$Cl_2 + CaO \rightarrow CaOCl_2.$$
Chlorine + Lime → Bleaching-powder

Articles to be bleached are saturated with a solution of the

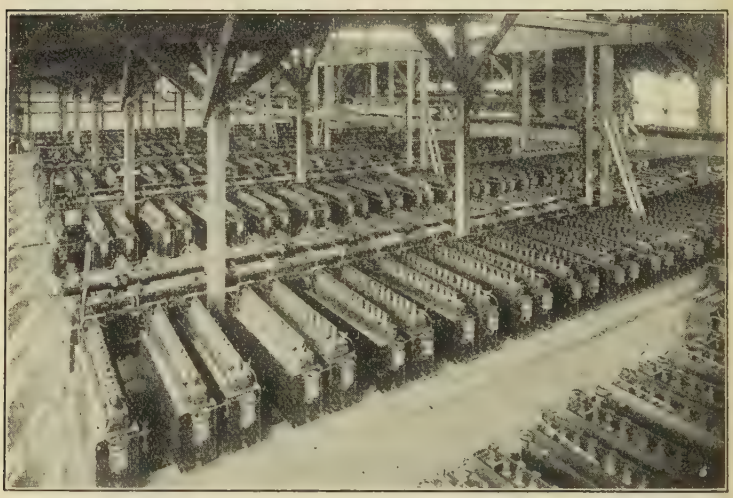


FIG. 329.—HUNDREDS OF ELECTROLYTIC CELLS
IN WHICH BRINE IS BEING SPLIT UP INTO HYDROGEN, CHLORINE, AND CAUSTIC SODA.

powder, left for some time so that oxidation of the colouring matter is complete, and then thoroughly washed. Wool and silk, being animal products, are of different composition, and bleaching powder is not suitable for them ; such animal products are bleached by the reducing action of sulphurous acid (Chapter XXXVII).

Chlorine being required on a large scale for the manufacture of bleaching powder, etc., several commercial processes for the production of the gas are in use. As mentioned in Chapter

XXXIV, large quantities of both hydrogen and chlorine are now obtained as by-products in the electrolysis of brine for the production of caustic soda. Electrolytic methods yield most of the chlorine used commercially (Fig. 329, 330).

In **Deacon's process,** invented many years ago, but still used in cases where less pure chlorine can be employed, the hydrogen of hydrochloric acid, gas, HCl, is oxidised by atmospheric oxygen to water, with the consequent liberation of the chlorine :

$$4HCl + O_2 \rightarrow 2H_2O + 2Cl_2.$$

The reaction is not so simple as it appears to be, however, since chlorine has a great affinity or liking for hydrogen, and ordinary atmospheric oxygen has difficulty in displacing it. But by the influence of copper chloride, Cu_2Cl_2, which acts as a catalyst (Chapter XXXIII), the necessary displacement of chlorine is achieved. Air and hydrochloric acid gas are mixed and passed through heated tubes containing pumice soaked with a solution of copper chloride. Though the copper compound is the same at the end of the reaction as at the commencement, it is believed that, reacting with the hydrochloric acid, it changes to cupr*ic* chloride during the process, and then becomes cupr*ous* chloride again by yielding up part of the chlorine :

$$2CuCl_2 \rightarrow Cu_2Cl_2 + Cl_2.$$

Cupric chloride — Cuprous chloride — Chlorine

Thus there are two chlorides of copper, one having more chlorine than the other (compare ferrous and ferric chlorides), and it is the cupr*ous* salt that here acts as a catalyst.

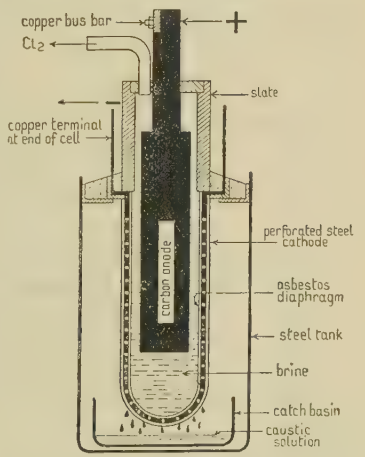


FIG. 330.—SECTION OF THE NELSON CELL USED FOR THE ELECTROLYSIS OF BRINE.

The strong affinity between hydrogen and chlorine causes a mixture of the two gases to explode under the influence of sunlight, and in the laboratory

this affinity can be demonstrated by plunging a piece of paper soaked in turpentine into a jar of chlorine gas. The turpentine consists of hydrogen and carbon ($C_{10}H_{16}$) and the chlorine captures the hydrogen, forming hydrochloric acid, while the carbon is set free as dense black smoke. In this case turpentine burns in chlorine, but the process is not one of oxidation as burning is in the ordinary way. Some melted metallic sodium placed in a jar of chlorine burns in a similar manner, forming sodium chloride or salt, and this synthetic method is, perhaps, the best way of demonstrating the fact that the metal sodium is one of the constituents of ordinary salt.

Chlorine is a member of a group of elements, collectively known as the **halogens**, a name signifying salt producers. The other members of this important group are **bromine**, a dark reddish irritating liquid at ordinary temperatures, **iodine**, a dark grey lustrous solid, and **fluorine**, a very active gas.

Since these elements form a well defined family, a table is given showing the relation between their atomic weights, the respective acids formed with hydrogen, etc.

	Fluorine : Gas.	Chlorine : Gas.
Atomic weight	19	35·5
Acid	Hydrofluoric, HF.	Hydrochloric, HCl.
Salt	Fluorides	Chlorides
	Bromine : Liquid.	**Iodine : Solid.**
Atomic weight	79·9	126·9
Acid	Hydrobromic, HBr.	Hydriodic, HI.
Salt	Bromides	Iodides

Bromides and iodides are used in medicine and in the laboratory, and calcium fluoride or fluorspar is a mineral employed in the production of **hydrofluoric acid** for etching patterns on glass. If a piece of glass is covered with a thin layer of wax and then a pattern traced by removal of the wax with a sharp pointed instrument, the glass so exposed will be decomposed or ' etched ' by the hydrofluoric acid fumes and the pattern is obtained as a permanent impression. The hydrofluoric acid is obtained by

placing fluorspar with strong sulphuric acid in a leaden dish, the reaction being

$$H_2SO_4 + CaF_2 \rightarrow CaSO_4 + 2HF.$$

The decomposition of the glass is due to the acid fumes reacting with the silica in the glass, forming silicon fluoride:

$$4HF + SiO_2 \rightarrow SiF_4 + 2H_2O.$$

The residual wax is washed off with turpentine.

HYDROCHLORIC ACID

In Deacon's process of chlorine manufacture, **hydrochloric acid** gas is necessary, and this is prepared by the action of strong sulphuric acid upon salt.

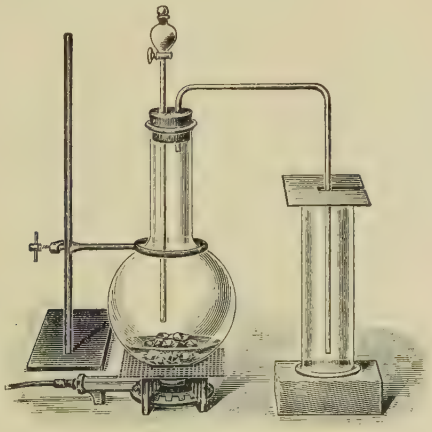


FIG. 331.

HOW DRY HYDROCHLORIC ACID GAS IS PREPARED AND COLLECTED IN THE LABORATORY.

In the laboratory the sulphuric acid and salt are placed in a glass flask and warmed, the gas which comes over is collected in a cylinder. The nature of the reaction which takes place depends upon the relative proportions of salt and sulphuric acid and upon the temperature.

With an excess of salt and at a higher temperature normal sodium sulphate is produced as a residue:

$$H_2SO_4 + 2NaCl \rightarrow \underset{\text{Normal sod. sulphate}}{Na_2SO_4} + \underset{\text{Hydrochloric acid gas}}{2HCl}.$$

But if the proportion of salt is smaller and the temperature kept low, only part of the hydrogen in the sulphuric acid is replaced by sodium, and sodium hydrogen sulphate is produced as a residue in the retort.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl.$$
$$98 \quad + \quad 58{\cdot}5 \quad = \quad 120 \quad + 36{\cdot}5$$

This is the reaction usually employed in the manufacture of hydrochloric acid, since there is considerable economy in the necessary heat. The student should find the molecular weights for the other equation above and work problems suggested by himself.

Hydrochloric acid is a colourless fuming gas at ordinary temperatures slightly heavier than air, and has a very irritating effect if inhaled. The acid fumes combine directly with those of ammonia, producing a white smoke of solid ammonium chloride.

$$\underset{\text{Ammonia}}{NH_3} + \underset{\text{Hydrochloric acid}}{HCl} \rightarrow \underset{\text{Ammonium chloride}}{NH_4Cl}.$$

Hydrochloric acid gas is very soluble in water, forming the solution sold as hydrochloric acid. On account of its preparation from salt it is sometimes called **spirits of salt,** and it is also known as muriatic acid, a name derived from muria, the Latin word meaning brine.

BAKING AND WASHING SODAS

The term soda was first used by the Italians to name plant ash containing sodium carbonate used for making glass. Formerly the ash of burnt seaweed supplied much of the sodium carbonate used commercially. At the present time the name soda is commonly applied to some form of sodium carbonate.

There are three common carbonates of this metal, two of them useful in the home, the third being of commercial importance.

When all the hydrogen in carbonic acid H_2CO_3 is replaced by sodium, the ordinary normal carbonate Na_2CO_3 is formed, and it is this carbonate that is manufactured extensively and used as a basis for the production of many other sodium compounds. Towards the end of the eighteenth century, when the supplies of soda from plant ash and natron were found to be insufficient for the manufacture of soap, glass, etc., Leblanc discovered a means of producing the carbonate by treatment of common salt with sulphuric acid. Hydrochloric acid is obtained as a by-product. Sodium sulphate or salt cake is thus formed, and by heating the salt cake with powdered coal, sodium sulphide is produced :

$$\underset{\text{Salt cake}}{Na_2SO_4} + 2C \rightarrow \underset{\text{Sodium sulphide}}{Na_2S} + 2CO_2.$$

The sulphide then reacts with powdered limestone producing the carbonate :

$$Na_2S + CaCO_3 \rightarrow Na_2CO_3 + \underset{\text{Calcium sulphide}}{CaS}.$$

Calcium sulphide being almost insoluble in water, it is easy to separate the sodium carbonate by solution and evaporation. The residue is then heated or *calcined* so that the anhydrous carbonate is obtained.

Though the Leblanc process is still employed at some places, the **ammonia-soda** or **Solway process** is commonly used (Fig. 332). In this process carbon dioxide gas obtained from special lime kilns is forced upwards through a solution containing salt and ammonia. The solution trickles down a tower containing numerous partitions, and as the carbon dioxide passes upwards ammonium bicarbonate, NH_4HCO_3, is formed. This reacts with the salt forming ammonium chloride, NH_4Cl, and sodium bicarbonate (*i.e.* the hydrogen carbonate of soda) :

$$(NH_4)HCO_3 + NaCl \rightarrow (NH_4)Cl + NaHCO_3.$$

The sodium bicarbonate (**baking soda**) is deposited upon the

partitions in the tower, and when heated gives off water and carbon dioxide, leaving the solid normal carbonate :

$$2NaHCO_3 \rightarrow H_2O + CO_2 + Na_2CO_3.$$

This behaviour of sodium bicarbonate under the influence of heat explains its use in the process of baking. The carbon dioxide evolved remains within the sticky dough and causes it to swell or rise, imparting a cellular structure to bread and cakes. The solid ordinary carbonate remains within the bread and gives it a rather unpleasant taste, and it also tends to hinder digestion by the introduction of an alkaline substance into the stomach. For these reasons it is usual to employ **baking powder,** which contains some substance such as cream of tartar, a slightly acid material which neutralises the sodium carbonate and at the same time produces a substance which is quite harmless. Bakers commonly employ yeast (Chapter V), which also brings about the liberation of carbon dioxide, causing bread to rise, the advantage of yeast being in the somewhat delayed evolution of the carbon dioxide.

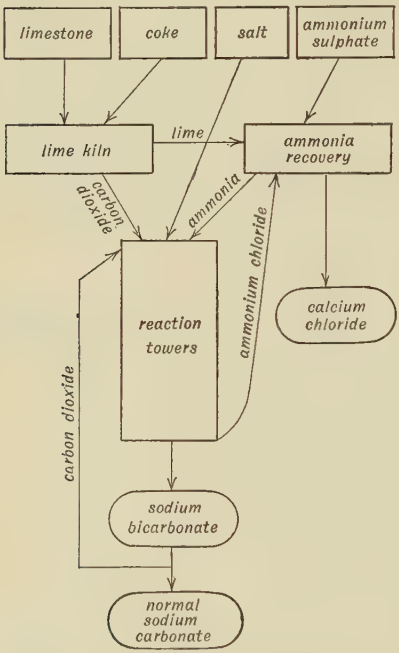


FIG. 332.

DIAGRAM REPRESENTING THE MANUFACTURE OF SODIUM CARBONATE BY THE SOLWAY PROCESS.

In **self-raising flour,** a carbonate capable of yielding carbon dioxide is added to the flour.

When ordinary sodium carbonate is dissolved in water and the solution allowed to evaporate, glassy crystals of hydrated

sodium carbonate having the composition $Na_2CO_3 \cdot 10H_2O$ are formed. This substance is known as **washing soda,** because it is employed in laundry work to soften water containing calcium salts. The equation below describes the reaction mentioned in Chapter XXXIV, where the softening of water containing calcium sulphate was mentioned :

$$CaSO_4 + Na_2CO_3 \cdot 10H_2O \rightarrow CaCO_3 + Na_2SO_4 + 10H_2O.$$

The calcium carbonate formed is precipitated, while the sodium sulphate, being a sodium salt, does not react with soap. Borax or sodium bi-borate, $Na_2B_4O_7 \cdot 10H_2O$, is sometimes added to water used for washing purposes as it prevents staining by iron compounds if such are present.

The ten molecules of water in washing soda are definitely combined with the carbonate and are described as water of crystallisation. Many other substances also require water of crystallisation in order to build crystals ; for example sodium sulphate, used as a medicine called **Glauber's Salts,** also require ten molecules of water, its formula being $Na_2SO_4 \cdot 10H_2O$. Crystals of alum have as many as 24 molecules of combined water. When such crystals are heated the water is driven off, leaving an *anhydrous* residue. Washing soda left exposed to the air at ordinary temperatures slowly loses its water of crystallisation, or *effloresces*, leaving a white powdery normal carbonate.

SPECTRUM ANALYSIS

The metals sodium and potassium are very much alike both in appearance and behaviour, though their atomic weights and other properties are different. Similarly, the compounds of potassium closely resemble the corresponding compounds of sodium. For example, potassium nitrate is so much like sodium nitrate that it can be used for the preparation of nitric acid in place of sodium nitrate if desired ; potassium chloride is a white solid very similar to salt, and so on. Sodium compounds are generally used, for the simple reason that they are of more widespread occurrence and therefore cost less.

All compounds of both metals are soluble in water, and it is not always easy to distinguish a potassium salt from a sodium one

by ordinary wet or dry chemical tests. But there is a simple method of identifying sodium, potassium, and many other substances. If a pinch of a sodium salt is placed upon a piece of clean platinum wire and held in the less coloured part of a bunsen flame, an intense yellow colour is imparted to the flame (Fig. 333). When a potassium compound is treated in the same manner, the colour imparted to the flame is a pale lilac. The wire used must be *perfectly clean* or the result will be more or less disguised.

Some other elements also give decided flame results, for example, copper colours the flame green, strontium red, and so on. These substances held in the flame are vaporised and the colour obtained is that of the glowing vapour. The principle can be applied to great numbers of elements if a delicate instrument called a **spectroscope** is employed (see also Chapter I). This consists of two telescopic tubes with a triangular glass prism placed between them. One of these tubes, the collimator, has an adjustable slit at the remote end through which light from the burning substance passes along the tube to the prism. In traversing the prism this light is refracted and dispersed so that an observer looking through the magnifying eyepiece at the end of the second tube sees a series of coloured vertical lines, the number, colour, and positions of which depend solely upon the nature of the substance being vaporised. These coloured lines constitute the **visible spectrum** of the glowing substance.

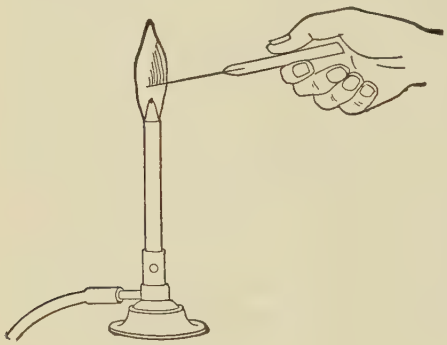


FIG. 333.
SODIUM COMPOUNDS AND MANY OTHERS GIVE CHARACTERISTIC COLOURS TO THE BUNSEN FLAME.

In the case of sodium, two yellow lines very close together are seen, while the spectrum of potassium consists of a bright violet line towards the violet end of the spectroscopic scale, together

with two red lines near the other or red end of the scale. When sunlight is passed through the spectroscope a complete range of colours from violet to red is seen—a continuous spectrum is the result. But with the glowing vapours of certain elements taken one at a time, a spectrum peculiar to each element only is seen. If a mixture of sodium and potassium compounds is vaporised, an observer sees the yellow lines due to sodium and the violet and red lines due to potassium in their correct positions, though in the actual flame the yellow glare produced by the sodium will mask completely the lilac coloration due to the potassium.

No other element can give the yellow lines caused by sodium, and no other element but potassium can give the particular red and violet lines due to that element. It is as if there were a row of reserved seats, a great number of them, and any particular element can occupy only the seat specially reserved for it. Thus in spectrum analysis we have a most delicate mode of detecting even minute traces of a substance. A trace of sodium compound, only $\frac{1}{100,000,000}$ of a grain, can be detected by spectroscopic means. This method of analysis, developed about the middle of the nineteenth century by **Bunsen** and **Kirchhoff**, has led to the discovery of elements, including the alkaline metals rubidium, caesium, also gallium and indium, the last named having a spectrum characterised by a bright indigo blue line. In cases where substances are not vaporised by the bunsen flame and a higher temperature is required, use is made of electric spark discharges which vaporise the substance.

The principle of spectrum analysis has been applied to astronomical work with most satisfactory results, as briefly outlined in Chapter I. The spectra or characteristic colours of gases may be observed when an electric discharge is passed through a glass discharge tube containing the gas under very reduced pressure. A practical application of this consists of tubes made in the shapes of letters, etc., and used for sign writing or other advertising designs. Commonly the tubes contain the atmospheric gas **neon**, which glows with a bright pale red colour.

CHAPTER XXXIX

NITRIC ACID, EXPLOSIVES, AND THE NITRATE INDUSTRY

The greater part of the atmosphere is composed of nitrogen which, so far as breathing is concerned, merely serves to dilute the oxygen. Nitrogen, unlike oxygen, passes in and out of the lungs without undergoing any chemical change. Though this element as it occurs in air is of no direct value physiologically, nitrogen *in a suitable form* is an absolute necessity for living things, both plants and animals. In the continuation of life as we know it, nitrogen plays a part second to no other element. The value of ammonia was indicated in an earlier chapter, and nitric acid and the salts called nitrates derived from it are among the other nitrogen compounds useful as plant food and in many other ways.

PREPARATION AND USES OF NITRIC ACID

Except at very high temperatures, nitrogen itself does not burn in air or oxygen and produce an oxide, but several oxides of nitrogen do exist and can be prepared in other ways.

One of these oxides, a white crystalline solid called **nitrogen pentoxide,** dissolves in water forming **nitric acid,** thus :

$$N_2O_5 + H_2O \rightarrow 2HNO_3.$$

But this is not the usual mode of preparing nitric acid ; in fact, the pentoxide is usually prepared by the reverse process, that of taking the water away from nitric acid.

Nitric acid is prepared in the laboratory and manufactured commercially by the treatment of sodium nitrate or saltpetre

with strong sulphuric acid, a double decomposition taking place, as expressed by the equation :

Saltpetre and Sulphuric Acid	yield	Sodium Hydrogen Sulphate and Nitric Acid
$NaNO_3 + H_2SO_4$	$\rightarrow$	$NaHSO_4 + HNO_3$
85 + 98	=	120 + 63

In the laboratory, the mixture is heated in a glass retort, but in manufacture on a large scale iron retorts are used. In either case the vapours of nitric acid are caught and condensed, in a glass vessel in the laboratory and in earthenware vessels in large scale manufacture. When the temperature is higher than it should be the sodium replaces all the hydrogen and normal sulphate of sodium is produced, thus :

$$2NaNO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2HNO_3.$$

Since nitric acid decomposes at high temperatures the supply of heat is regulated, so that the reaction produces the sodium hydrogen sulphate as in the former reaction expressed above. Even at the lower temperature some acid is apt to decompose

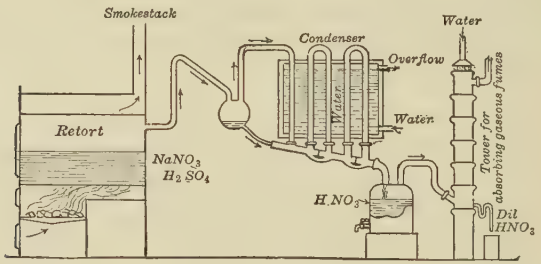


FIG. 334.
DIAGRAM OF THE INDUSTRIAL PROCESS FOR THE MANUFACTURE OF NITRIC ACID.

yielding oxides of nitrogen, which dissolve in the acid formed, giving it a brownish colour. Other impurities such as chlorine and iodine occurring in the saltpetre also pass over with the fumes of nitric acid, hence, for purposes where pure acid is required, it must be purified by redistillation.

According to the molecular weights of the substances used

and produced, 85 parts by weight of saltpetre and 98 parts of sulphuric acid yield 63 parts of nitric acid. Assuming there is no loss, what weight of nitric acid can be obtained from one ton of saltpetre treated with the necessary amount of acid ?

Since 85 tons of nitrate yield 63 tons of acid, one ton of nitrate yields $\frac{63}{85}$ of a ton of acid, and this simplified, gives approximately 14 cwt. 93 lb.

How are these weights modified if potassium nitrate, KNO_3, with a molecular weight of 101 is employed in place of saltpetre ? Since the sodium salt is cheaper than nitre it is always used in the commercial preparation of the acid, though nitre is sometimes used in the laboratory.

Strong nitric acid is a liquid about one and a half times as heavy as water, fumes in moist air, and is of a highly corrosive character, producing bad sores if allowed to come in contact with the naked hands. This action is due to its powerful oxidising power, a feature which can be demonstrated in many other ways. Thus a few drops of the acid placed upon dry sawdust causes it to take fire, the sawdust burning at the expense of oxygen supplied by the nitric acid.

Experiments of this sort should be performed only by experienced persons, strong acids being dangerous. Different metals react in differing degrees with nitric acid, but in some cases a most marked action takes place. Thus with copper it reacts, producing copper nitrate and brown fumes of oxide of nitrogen, and on account of this action it is employed for engraving designs upon copper.

EXPLOSIVES

When such substances as carbon and sulphur burn in the ordinary way, the rate at which the reaction takes place is relatively slow and the gaseous oxides produced can be collected and examined. But if such substances are completely and instantaneously oxidised by some powerful oxidising agent, there is a sudden production of huge quantities of heated gas which require a space some hundreds or even thousands of times as great as that occupied by the original solid material.

Consequently such gases instantaneously exert an enormous pressure and cause a violent explosion, when the space occupied by the original solid is inadequate. Loose gunpowder on the ground burns with a sudden flash but does not explode, though gunpowder placed in a closed space and then fired by electricity or by a fuse causes an explosion. The imprisoned gases may burst the walls of the enclosing material.

Nitric acid is particularly suitable for the manufacture of explosives, because it is such a powerful oxidising agent, and because it combines with certain organic substances forming **nitro-derivatives** of an explosive character. Organic substances contain much carbon, so that by their combustion much gaseous oxide of carbon is produced. Glycerine is such an organic substance, and when combined with nitric acid a particularly dangerous compound called **nitro-glycerine** (glyceryl nitrate) is formed :

$$\underset{\text{Glycerine}}{C_3H_5(OH)_3} + 3HNO_3 \rightarrow \underset{\text{Nitro-glycerine}}{C_3H_5(NO_3)_3} + 3H_2O.$$

When the nitro-glycerine explodes, the carbon is all oxidised to carbon dioxide, and large quantities of free nitrogen are also produced :

$$4C_3H_5(NO_3)_3 \rightarrow 12CO_2 + 6N_2 + O_2 + 10H_2O.$$

Nitro-glycerine being too 'touchy,' and exploding when it receives a mechanical shock, other kinds of explosive that can be transported safely are now in common use for military or other purposes.

High explosive shells contain a substance known as **trinitro-toluene,** popularly designated **T.N.T.,** formed when the organic compound toluene is heated with nitric acid :

$$\underset{\text{Toluene}}{C_6H_5CH_3} + 3HNO_3 \rightarrow \underset{\text{T.N.T.}}{CH_3C_6H_2(NO_2)_3} + 3H_2O.$$

This product can be melted easily at a fairly low temperature (81·5°), and so can be poured into shell cases. Since mechanical shock does not explode T.N.T., the shells can be moved safely from place to place, but it explodes with great violence when operated by a **detonator** placed within the shell.

There are several types of firing apparatus or detonator, many being in the form of percussion caps containing fulminate of mercury, $Hg(OCN)_2$, which explodes when a shell strikes a target. In other cases the effect is slightly delayed so that the projectile

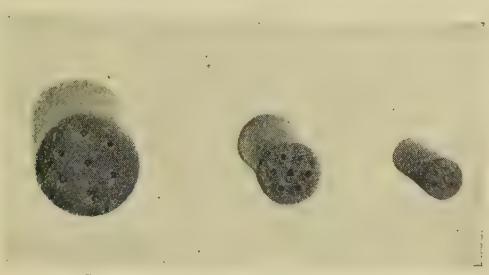


FIG. 335.—SMOKELESS POWDER.

explodes after it has penetrated an armour plate or other obstruction.

Large quantities of the gases carbon monoxide and nitrogen are produced by combustion of T.N.T. in addition to a considerable amount of free carbon :

$$2CH_3C_6H_2(NO_2)_3 \rightarrow \underset{\text{Carbon monoxide}}{7CO} + 3N_2 + \underset{\text{Carbon}}{7C} + 5H_2O.$$

The carbon is responsible for the black smoke produced. In the explosion of gunpowder a grey smoke is produced and is considered to be due to the formation of much solid potassium carbonate. Smoke consists of *solid* particles. Gunpowder itself is not a nitro-derivative, but a mixture of carbon and sulphur with nitre, and its combustion results in the formation of large quantities of carbon dioxide and free nitrogen.

In modern times **smokeless explosive** is commonly employed (Fig. 335), an example being **guncotton,** made by treating cotton with nitric acid :

$$\underset{\text{Cotton}}{C_{12}H_{20}O_{10}} + 6HNO_3 \rightarrow \underset{\text{Guncotton}}{C_{12}H_{14}O_4(NO_3)_6} + 6H_2O.$$

But guncotton is too touchy, and a more suitable material called

cordite is prepared by mixing guncotton, nitro-glycerine, and vaseline together in the proportions 65, 30, and 5 respectively. As no solid products are obtained when the explosion occurs, cordite produces no smoke.

It is necessary to distinguish between the explosion in the gun which propels the projectile and the later explosion which occurs when the projectile finds its mark. The charge of T.N.T. explodes when the shell reaches the objective, but the projectile is propelled by the explosion of cordite in the cartridge behind the shell in the gun. Small shells, and also rifle bullets are fitted into the end of a brass or copper cartridge case which contains the propelling charge and also a detonator.

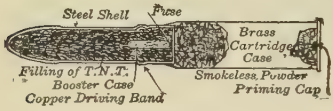


FIG. 336.—MODERN PROJECTILE USED IN THE FAMOUS FRENCH 75 MM. GUN.

The shell or rifle bullet is forced out of the gun at great velocity by the pressure of the gaseous products of the rapid combustion or explosion of the propellant. For rockets used in throwing life-saving apparatus from the shore to a ship, or for making signals, and those used in firework displays, a different kind of propellant is used. A comparatively slow burning substance is used which throws out a steady stream of gaseous products from the hinder end of the rocket. This stream of hot gases thrusts the rocket forward. A succession of powerful rockets has been used experimentally to propel a car, and it has been suggested that they might be employed to drive aeroplanes.

For mining purposes **dynamite**, the active part of which is nitro-glycerine, is employed. A mixture is made up of such composition that the explosion is not sufficient to pulverise the coal or other mineral, but merely breaks it up into large pieces. This moderating effect is obtained by the addition of alkaline nitrate and flour to a material resembling cordite.

The composition and manufacture of fireworks are trade secrets, but such substances consist of inflammable powder mixed with compounds which gives distinct colours to the flame. Thus, strontium nitrate gives a red colour, copper or barium

compounds green, and so on. Iron filings produce sparks, as in squibs.

Substances related to guncotton are not always used for explosive purposes. A similar compound with less nitric acid and treated with alcohol and camphor produces **celluloid,** used for photographic films, accumulator cases, knife handles, combs, etc. Some varieties of **artificial silk** are also manufactured from guncotton. **Picric acid,** another nitro-derivative formed by the combination of nitric and carbolic acids, not only forms the explosive called **lyddite,** but being of a characteristic yellow tint is also employed as a dye-stuff. It is also a useful antiseptic.

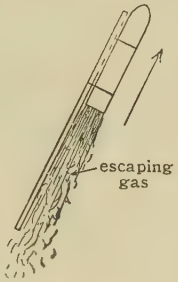


FIG. 337.
THE SUDDEN RUSH OF GAS DOWNWARDS PROPELS A ROCKET UPWARDS.

NITRATES AND THE NITROGEN PROBLEM

In gunpowder, potassium nitrate, the potassium salt derived from nitric acid, is used as an oxidising agent in place of the acid itself. If this nitrate is dissolved in water, and then porous paper is dipped in the solution, a ' touch ' paper or fuse is obtained when the material is dry. The nitrate on the paper ensures that the latter smoulders when once ignited. Instead of paper, straw or other materials may be soaked in nitre solution and used for the same purpose.

Nitrates are salts formed by the replacement by a metal of the hydrogen in nitric acid, but it must be understood that the mere addition of a metal to the acid does not always result in a simple reaction producing a nitrate. Since the action of nitric acid on copper is used in engraving and by jewellers as a test to distinguish between gold and copper, the equation representing the reaction may be given here :

$$3Cu + 8HNO_3 \rightarrow \underset{\text{Copper nitrate}}{3Cu(NO_3)_2} + \underset{\text{Nitric oxide}}{2NO} + 4H_2O.$$

The reaction is by no means so simple as that which occurs when zinc is placed in sulphuric acid.

The nitric oxide produced is a colourless gas but it reacts with the oxygen of the air forming reddish brown fumes of nitrogen peroxide, N_2O_4. The green copper nitrate, as all other nitrates, is soluble in water, this one forming a characteristic green solution. Many copper compounds are of a green or blue colour, and when vaporised in a bunsen flame impart a green flame to it.

Nitric acid may be regarded as consisting of two parts combined together, hydrogen and the group (NO_3), which is known as the *acid radicle* of this particular acid just as (SO_4) is the acid radicle of sulphuric acid.

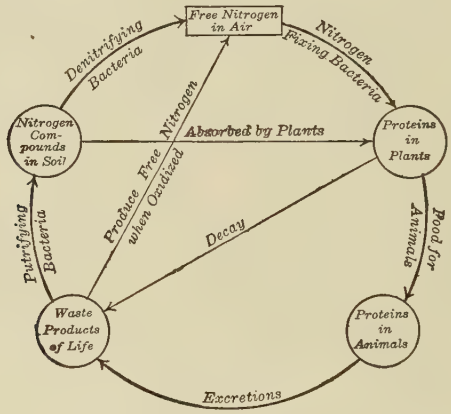


FIG. 338.
DIAGRAM OF THE NITROGEN CYCLE IN NATURE.

Now, if the hydrogen is replaced by a monovalent metal, say potassium, only one of the acid radicles is required to form the nitrate. Thus the formula for potassium nitrate is KNO_3. But in the case of copper two acid radicles are required, and the formula representing copper nitrate is therefore $Cu(NO_3)_2$. The divalent copper has replaced the hydrogen in 2 molecules of nitric acid. Similarly, the composition of the nitrate of the divalent metal calcium is expressed by $Ca(NO_3)_2$.

Nitric acid and nitrates dissolved in water percolating through the soil form the source from which plants obtain the necessary supplies of nitrogen required for the building up of new proto-

plasm or living matter (Fig. 338). Soil which has been used year after year becomes deficient in nitrogenous material, and consequently cannot support plant life to the same extent as before. Impoverished soil can be improved by the addition of farmyard manure or one of the so-called artificial manures—nitrates and ammonium sulphate. The synthetic preparation of the latter has been described previously (see Chapter XXXVI).

Large quantities of natural sodium nitrate occur as a deposit in the ground in the rainless district of Northern Chile (Fig. 339).

FIG. 339.—GENERAL VIEW OF NITRATE OF SODA GROUNDS AND WORKS, CHILE.

The earthy nitrate or *caliche* is mined by blowing it up with explosives ; the nitrate is refined by treatment with water and recrystallisation.

Most of the world's supplies have been obtained from Chile, but the nitrate deposits there will not last for ever, and already the supplies from that source are inadequate. Some years ago the late **Sir William Crookes** directed attention to the fact that unless some mode of manufacturing nitrates from the nitrogen in the atmosphere were discovered, the human race would soon be faced with an insufficient food supply.

Fortunately, the last few years have witnessed several successful attempts to solve this problem, and now adequate supplies of nitrogen compounds are manufactured synthetically, the atmosphere affording a practically inexhaustible source of nitrogen.

The material required for the production of nitrates is of course nitric acid, and this is prepared by dissolving an oxide of nitrogen in water.

There are several oxides of nitrogen, and in the **Birkeland-Eyde process** (Fig. 340) employed in Norway, where electricity is produced cheaply by water power, the first stage of the process is the combination of atmospheric nitrogen and oxygen to form nitric oxide, NO. In ordinary circumstances these two gases do not combine, but under the influence of a large electric arc discharge, which has an exceedingly high temperature (about 3000°), some of the oxygen and nitrogen combine to produce nitric oxide. The air is forced through the arc flame, which is spread out by

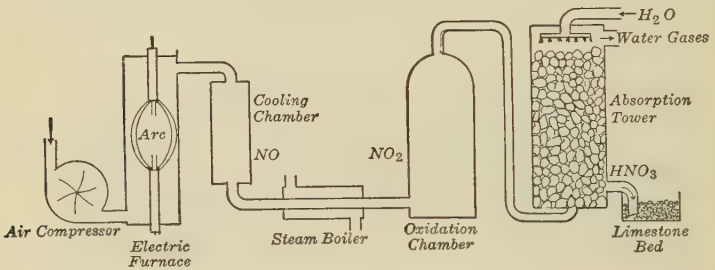


FIG. 340.

DIAGRAM OF THE BIRKELAND-EYDE PROCESS FOR THE FIXATION OF ATMOSPHERIC NITROGEN.

the influence of strong electro-magnets. On cooling, the nitric oxide combines with more atmospheric oxygen, producing nitrogen peroxide $2NO + O_2 \rightarrow 2NO_2$. Then the peroxide is passed up towers down which water is trickling and nitric acid is formed. $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$. Some nitric oxide also produced is made to combine with more atmospheric oxygen and is thus used up. The nitric acid obtained is then converted to a metallic nitrate by being brought in contact with limestone, $2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$. Calcium nitrate is produced and in this form the substance, often called Norwegian nitrate, is suitable for transport, and is extensively used for soil improvement.

So early as 1784 Cavendish showed that atmospheric oxygen and nitrogen under the influence of the electric spark combine to

form oxide of nitrogen, and the Birkeland-Eyde method of nitrogen fixation, invented in 1905, also a very similar process invented by **Siemens and Halske** in 1902, are practical applications of this observation. The special feature of these methods lies in the spreading out of the electric arc flame by a powerful magnetic field, instead of using electric sparks.

Another entirely different mode of nitrogen fixation is known as the **cyanamide process,** in which nitrogen obtained from liquid air combines with calcium carbide, producing a compound called calcium cyanamide, $CaCN_2$. The reaction is expressed by the equation

$$CaC_2 + N_2 \rightarrow CaCN_2 + C.$$

The mixture of cyanamide and carbon forms a good fertiliser known as **nitrolime.**

In both synthetic ammonia and nitrolime the nitrogen is ultimately derived from the air.

While man has only just recently discovered means of fixing atmospheric nitrogen and converting it to a form suitable for plant requirements, certain plants themselves, members of the pea and bean order (*Leguminosae*) have, with the aid of bacteria in the soil, been fixing nitrogen for a very long time, the actual duration of which cannot be calculated (see Chapter VI). These bacteria have been cultivated, and the cultures sold under the name **nitragen.**

Apart from agriculture, many nitrates are useful in the arts. Silver nitrate is employed in photography and sometimes forms an electrolyte for silver plating.

OTHER OXIDES OF NITROGEN

Three oxides of nitrogen, namely, nitric oxide, NO, nitrogen peroxide, N_2O_4, and nitrogen pentoxide, N_2O_5, have been mentioned above, and there are two others, nitrogen trioxide, N_2O_3, and nitrous oxide, N_2O. The trioxide is a pale bluish liquid at a temperature of about $-30°$, but above this temperature it dissociates into nitric oxide and nitrogen peroxide. On being cooled again these reunite, producing the trioxide. This affords another case of a reversible reaction :

$$2N_2O_3 \rightleftarrows 2NO + N_2O_4.$$

Nitrous oxide is a much more useful compound on account of its anesthetic properties and is often employed by dentists. It is a colourless gas having a slight odour, and may be prepared by heating ammonium nitrate :

$$NH_4NO_3 \rightarrow 2H_2O + N_2O.$$

The evolution of the gas is rapid, and as both the products are gaseous at the temperature, some ammonium nitrate heated in a test tube suddenly disappears. A more steady supply of nitrous oxide is obtained when a mixture of ammonium sulphate and sodium nitrate is heated. The gas was discovered by **Priestley** in 1772, who also discovered oxygen two years later, and it is interesting to note that both of these gases rekindle a glowing splinter. It is easy to distinguish between the two gases, however, since a little nitric oxide, NO, added to oxygen produces red fumes of nitrogen peroxide, N_2O_4, but if added to nitrous oxide, there is no visible change.

The physiological effects of nitrous oxide vary with different persons, though all become insensible for a short time, if sufficient gas be inhaled ; smaller quantities produce hysteria, causing some people to weep, others to laugh for no apparent reason, hence the name **laughing gas** sometimes applied to the substance.

Since the oxides of nitrogen furnish an excellent example of the law of multiple proportion, it may be as well to give here a brief table showing the various atomic proportions and chief properties of these compounds.

TABLE OF THE OXIDES OF NITROGEN

Nitrous oxide N_2O colourless gas forms hyponitrous acid HNO.	Nitric oxide NO colourless gas —	Nitrogen trioxide N_2O_3 blue liquid at $-30°$ forms nitrous acid HNO_2.
Nitrogen peroxide N_2O_4 reddish-brown gas —		Nitrogen pentoxide N_2O_5 solid white forms nitric acid HNO_3.

The acids are formed by combination with water.

Observations upon the vapour density of nitrogen peroxide show that at high temperatures this substance dissociates, forming less complicated molecules having the composition NO_2. On cooling, these molecules again unite forming the heavier molecules N_2O_4. The action is thus reversible and may be expressed by :

$$N_2O_4 \rightleftarrows NO_2 + NO_2.$$

CHAPTER XL

SOME METALS OF EVERYDAY LIFE

METALS play a more important part in our affairs than is apparent at first sight. Everyone is familiar with iron nails, pipes, etc., lead piping, copper kettles, aluminium saucepans, steel knives and other articles, silver and bronze coins, brass fittings, and many other indispensable metallic objects.

But apart from these objects, metals occur combined with other elements forming substances which do not look at all metallic. Thus the metal sodium is present in common salt and in washing soda, aluminium is an essential part of clay, and calcium occurs in lime.

Metals are elements possessing distinct properties which easily distinguish them from another class of elements called non-metals, though there are some elements having properties intermediate between these two classes.

What are the characteristic features or properties of metals? An answer to this may be given by a comparison of a typical metal, say iron, with a typical non-metal, such as sulphur.

An iron nail is hard and tough, though malleable, that is, it can be hammered flat; and it is ductile or capable of being drawn out into thin strands. It also conducts electricity and heat, and a fresh surface reflects light well. Iron melts at a high temperature and is non-inflammable though it slowly oxidises, forming rust. Oxides of iron and those of other metals have basic properties; they do not form acids as most oxides of non-metals do. Many metals dissolve in common mineral acids liberating hydrogen.

Now a non-metal, for example sulphur, has properties which are in almost every case the direct converse of these. Sulphur is

not particularly hard, it is not malleable, neither can it be drawn into threads while still solid. It is a bad conductor of heat and electricity, and its surfaces are not particularly good reflectors of light. Polished iron makes a good mirror, sulphur does not. Sulphur melts at a relatively low temperature and is very inflammable, its oxidation producing an acid. Though sulphur is a solid, some non-metals are liquid (bromine) or gaseous (oxygen) at ordinary temperatures, and in this respect differ from metals, which are all solid, with the exception of mercury.

HOW IRON AND STEEL ARE OBTAINED

Only very rarely is metallic or native iron found in Nature, all of the sources or mineral ores from which the metal is obtained being compounds of iron with other elements. The more important of these iron ores are the carbonate and the oxide.

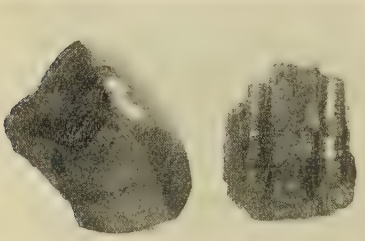


FIG. 341.—IRON ORES.
KIDNEY-SHAPED HAEMATITE ON THE LEFT, LIMONITE WITH STALACTITIC HABIT ON THE RIGHT.

Iron carbonate, $FeCO_3$, known in mineralogy as **chalybite** or **siderite,** occurs sometimes in crystalline forms, but more often mixed with a certain amount of clay forming brownish earthy nodular masses called **clay ironstone.** This is the type of iron ore commonly found in the rocks named the Coal Measures, and accounts for the fact that nearly all the coalfields are also districts where extensive iron smelting is carried on.

Red iron oxide, Fe_2O_3, is known as **haematite** and occurs as a deposit filling cavities and veins in rocks, as in the district north of Barrow-in-Furness, where large ' pockets ' containing haematite are found in limestone.

By combination with water the red oxide has in some cases changed to a brown hydrated oxide, $Fe_2O_3xH_2O$, called **limonite,** in which the proportion of water is variable. In other cases, beds

of rock originally formed as carbonate have been altered to brown limonite, the Northamptonshire ironstones being of this type. In cases of this sort, where iron ore is found in definite beds, it appears that rocks originally formed as limestones have been subjected to chemical alterations, first the substitution of iron in place of calcium, thus producing iron carbonate, and then the reduction of the carbonate to the form of oxide.

The black oxide of iron, Fe_3O_4, known as **magnetite,** since it sometimes exhibits magnetic properties, is of rarer occurrence in the British Isles, though great quantities of it occur in Scandinavia and the eastern portion of North America. **Pyrites** or sulphide of iron, FeS_2, is employed as a source of sulphur dioxide for the manufacture of sulphuric acid (Chapter XXXVII) and is not called an ore of iron in the metallurgical sense.

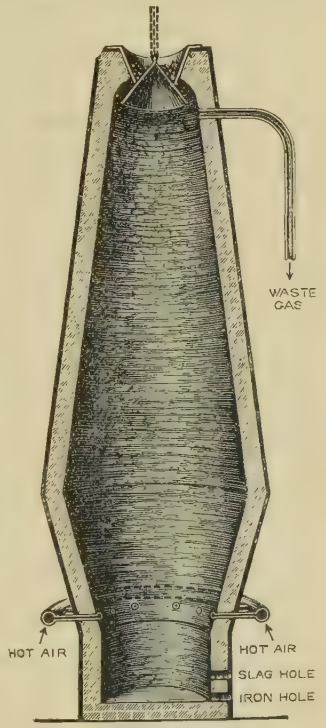


FIG. 342.—A BLAST FURNACE USED FOR IRON SMELTING.

In the process of obtaining iron from its ores, or smelting, the ore is first calcined, that is, arranged in stacks with fuel, and heated. This converts any ferrous material to the ferric state. Calcined ore, limestone, and coke are then placed in a large **blast furnace** consisting of an almost cylindrical structure about 80 feet in height and about 20 feet at its widest diameter (Fig. 342). The furnace is lined with heat-resisting fire-bricks. The materials are fed into the furnace at the top, where a cone-shaped structure fits against a cup-like arrangement for receiving the ore, etc. Numerous openings or 'tuyeres' admit a blast of hot air near the base of the furnace,

such air being heated by gases descending a wide pipe connected to the top end of the blast furnace. These gases are passed to a separate furnace known as Cowper's stove.

Limestone is put in with the ore and coke, because it helps to melt the ore and form a molten slag which can be separated from the iron. A substance which acts in this way is called a **flux,** and enormous quantities of limestone are quarried in England for this purpose. The coke burns, and in these circumstances forms carbon monoxide, CO, a gas which is a very good reducing agent and readily combines with more oxygen to form carbon dioxide, CO_2. The additional oxygen is supplied by the iron ore, which is thus reduced to the metallic condition. Thus, if the ore is haematite :

$$Fe_2O_3 + 3CO \rightarrow 3CO_2 + 2Fe.$$

Some of the carbon monoxide yields free carbon :

$$2CO \rightarrow CO_2 + C,$$

which is partly absorbed by the melting iron, and the quality of the **pig iron** finally obtained depends largely upon the amount of carbon in it. More free carbon yields grey pig iron, and less free carbon yields white pig iron, but some of the carbon is in combination with the iron and there is more of this combined carbon in the white pig. In either case the proportion of carbon is generally less than 3 per cent.

At the base of the blast furnace the molten iron and molten slag collect ; the slag, being lighter, is above the iron, and each is run off periodically. The iron is run into moulds made of sand, and solidifies, forming pigs or bars about 3 feet long and 3 or 4 inches in diameter. The slag when cool is collected into heaps and may be used as road metal, ballast, or in some cases as a constituent of cement.

Pig iron is the form of the metal from which the useful substances cast iron, wrought iron, and steel are made.

Cast iron is simply pig iron cast in suitable moulds, such iron being brittle, not malleable, crystalline in texture, and incapable of standing severe shocks. On account of these properties it is only suitable for ornamental ironwork, and articles not meant to be subjected to any great strain. The more valuable **wrought iron** is fibrous in texture and is tough and malleable, so that it can

be drawn into wire, rolled into plates, etc. ; hence it is the form of iron with which we are most familiar, being used for nails, horseshoes, wire, and many domestic articles and agricultural implements. Iron softens before it actually melts, consequently it can be welded.

In the manufacture of wrought iron, ordinary pig iron is melted in the presence of iron scraps and haematite, the operation being carried out in a reverberatory furnace, or one which shakes the material as it heats it.

The temperature at which wrought iron melts is about 1550°, some 250° higher than the melting point of cast iron.

The most valuable and important of all the iron products is **steel,** which contains less carbon than does cast iron, but more than wrought iron. Consequently it may be manufactured either by adding carbon to molten wrought iron or by taking away carbon from cast iron. In the **Siemens-Martin process** of steel manufacture the two kinds of iron are fused together in a furnace, the deficiency of carbon in wrought iron being balanced by the greater amount in cast iron. Typical steel contains about one per cent. of carbon.

In another method known as the **crucible process,** wrought iron is melted with the necessary amount of carbon in large crucibles composed of fire clay. Steel prepared in this way makes a high grade material employed mostly for the manufacture of tools.

By far the greatest quantity of steel is produced by the **Bessemer process** (patented in 1856), in which air is forced through a mass of molten wrought iron contained in a large egg-shaped vessel called a converter ; this vessel is made of iron and lined with fire-resisting material, either silicate or dolomite.

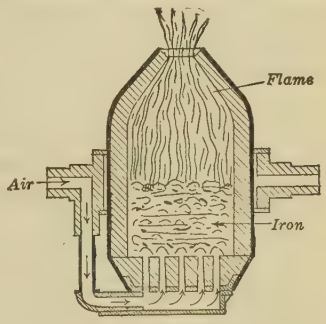


FIG. 343.—A BESSEMER CONVERTER.

By this means the wrought iron is purified, and then the necessary carbon is added in the form of a substance called *spiegeleisen*, a compound of iron and manganese containing a definite propor-

tion of carbon. After the air blast has been applied again, the molten steel can be run into moulds.

When the lining of the converter is composed of silica or silicate the product known as *acid steel* is obtained, and this contains a certain amount of phosphorus which makes the steel brittle. In the year 1878, **S. G. Thomas** introduced his **basic Bessemer process** in which dephosphorised steel is produced in a converter lined with dolomite, a mineral which is not a silicate (Chapter XLI). Since the introduction of the basic process the world's annual production of steel has risen from three million tons to about one hundred million tons.

The great advantage of the Bessemer process is its quickness, compared with the time taken by other methods. A converter can hold about 10 tons of molten iron, and this can be converted to steel within half an hour.

Steel suddenly cooled after being heated to a high temperature becomes very brittle and hard, so that it can even scratch glass. Cutting tools are made of steel and the cutting edges are hardened in this way. Variations in *temper* are obtained by reheating such hardened steel and then allowing it to cool under varying conditions. The temper also largely depends upon the chemical composition of the steel, however. Chrome steel, containing chromium (see below), is a hard drill-proof metal employed for the manufacture of commercial safes and for crushing and stamping machinery. Both nickel and chromium are used in the production of tough armour plates employed on warships, etc., while stainless cutlery is composed of a similar chromium steel. The presence of a little manganese also makes very hard steel, which is used for armour plate, junction rails and points on tramways, etc.

Since ordinary steel has a tendency to rust, it may be protected by a superficial layer of the non-rusting metal, tin, producing tinned plate, mentioned with galvanised iron in Chapter XXXIII.

OTHER USEFUL METALS AND THEIR ALLOYS

The actual discovery of metals is a matter over which time has drawn a veil, but it may reasonably be assumed that the earliest metallurgists were prehistoric men who lived during the period

following the neolithic or new stone age, and the materials with which they worked were probably copper and gold, since they occur native, or in the metallic condition. This being the case, the earliest metal workers were not concerned with smelting operations, though the production of bronze, an alloy, must have followed soon afterwards.

Metallic copper is of a reddish-brown colour, is malleable and ductile, melts at 1082·6°, does not easily oxidise, though in the presence of water and carbon dioxide it corrodes by the formation of a green basic carbonate commonly known as *verdigris*. Native copper is not plentiful enough for human needs, hence most supplies of copper are obtained from either the mineral oxide, Cu_2O, called **ruby ore,** or a sulphide such as **copper glance,** Cu_2S, or **copper pyrites,** $CuFeS_2$.

These copper ores, together with tinstone or **cassiterite,** SnO_2, the ore of tin, occur in mineral veins traversing igneous rocks, such as granite, hence the chief localities where they are found in England are the granite districts of Cornwall and South Devon. The chief supplies of copper ores come, however, from the United States. It is believed that these substances were deposited by the condensation of metalliferous vapours forced along cracks and cavities in the heated granite mass.

Of the copper ores, the oxides are much more easily reduced to the metallic state than are the sulphides, merely heating in a blast furnace with coke being sufficient. Carbon monoxide is formed by the burning coke, and this reduces the copper oxide, thus :

$$Cu_2O + CO \rightarrow CO_2 + 2Cu.$$

When the ore is a sulphide it must be first converted to oxide by being roasted in the presence of air.

Pure copper is obtained from the crude metal by electrolysis (Fig. 344).

In its practical applications, copper is second only to iron. Since the metal is such a good conductor of electricity, the electrical industries alone use enormous quantities, chiefly in the form of wire ; boilers, kettles, rivets, and nails are composed of copper, because it does not rust, and since it corrodes only very slowly in water it is employed to form an outer casing on ships.

Mixtures of metals in certain proportions are called **alloys,** and such mixtures are better for some purposes than one metal by itself. In British bronze coins copper forms 95 per cent. of the alloy, the rest being tin, 4 per cent., and zinc, one per

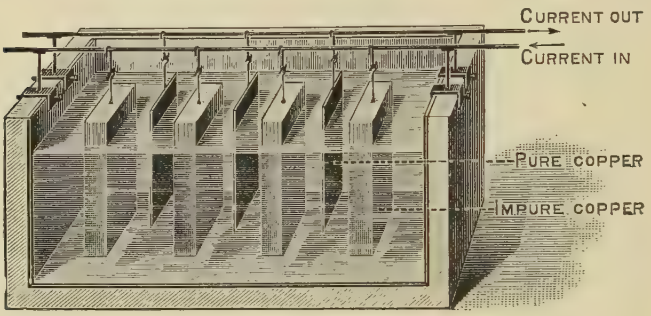


FIG. 344.
THE PURIFICATION OF COPPER BY MEANS OF ELECTROLYSIS.

cent. In ornamental bronze the proportions vary. Copper is also present in gold and silver coins. Other alloys containing copper are brass, bell metal, gun metal, and German silver. The metals present and their relative proportions in these alloys are :

In common brass -	copper	66	per cent.	zinc	34	per cent.		
„ bell metal -	„	75	„	„	zinc	25	„	„
„ gun metal -	„	90	„	„	tin	10	„	„
„ German silver -	„	56	„	„	nickel	24	„	„
					and zinc	20	„	„

In type metal used by printers, lead, antimony, and tin are present in the relative proportions of 75, 20, and 5 respectively. The molten metal is forced into ' dies ' or moulds containing an impression of the letters or figures, and the presence of antimony, which expands slightly on solidification, ensures a sharp definition of the type.

The separation of tin from cassiterite closely resembles the extraction of copper from its ores. The cassiterite is washed and then roasted to remove impurities, such as arsenic or sulphur. A powerful electro-magnet then removes tungsten (valuable for

filaments of electric lamps), and the ore is placed in a blast furnace with fuel, the oxide then being reduced :

$$\underset{\text{Cassiterite}}{SnO_2} + 2C \rightarrow 2CO + \underset{\text{Tin}}{Sn}.$$

The crude tin thus obtained is refined by being melted, the impurities collecting as a surface ' dross ' which can be removed. In addition to its use for tinned plate and tinned iron, employed for canning purposes, the metal is employed for electric fuse wires, and forms an amalgam with mercury for the backing of mirrors. A particularly useful alloy of tin and lead is called **solder,** and is used for joining pieces of metal together firmly. Though the proportion of the metals in solder vary, typically there are equal quantities of tin and lead. Another alloy of these two metals containing 75 per cent. of tin is **pewter,** much used in earlier times for mugs, tankards, salvers, and similar objects.

Metallic lead is obtained from the dark crystalline lustrous mineral sulphide called **galena,** PbS, which like the ores of copper and tin is believed to have been deposited by vapours cooling in cracks traversing rocks. But whereas rocks of the igneous type form the chief ' country ' for tin and copper, lead ore is found principally as veins in limestone regions.

Hundreds of disused shafts in the Carboniferous limestone districts of the Pennines and Mendip Hills testify to the lead-mining activities of former times. The ore was certainly mined in these districts during the Roman occupation, but at the present time the industry in England is not in a flourishing condition. In Derbyshire the lead ore is often found intimately mixed with barytes or barium sulphate and these substances are separated by crushing and washing.

On being heated in a furnace some galena is oxidised, with the production of lead oxide and lead sulphate, both of which react with other portions of galena, resulting in the formation of metallic lead and sulphur dioxide. Thus :

$$2PbO + PbS \rightarrow 3Pb + SO_2 \quad \text{and} \quad PbSO_4 + PbS \rightarrow 2Pb + 2SO_2.$$

The metal so obtained usually contains antimony and an amount of silver sufficiently great to be worth separation. In the

desilverization of lead by **Parke's process,** molten zinc is mixed with the molten lead, with the result that the zinc combines with silver to form an alloy which, as the mixture cools, collects at the surface of the liquid and can be raked off (Fig. 345). Afterwards the zinc and silver are separated by distilling the alloy.

The extensive use of metallic lead for piping, roofing, cisterns, evaporating pans in chemical works, accumulator plates, bullets, shot, etc., is due to its softness, which enables it to be moulded easily at ordinary temperatures, its weight, its power of resisting

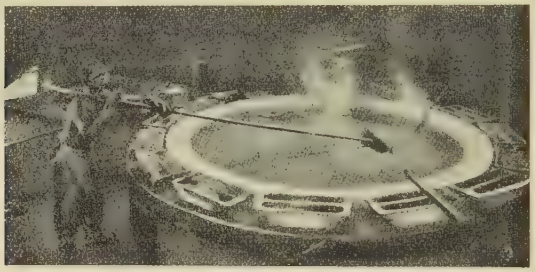


FIG. 345.—EXTRACTING SILVER FROM LEAD
BY USE OF A LAYER OF MELTED ZINC.

oxidation, and its stability in the presence of many concentrated acids, sulphuric for example.

On the other hand, nitric and certain organic acids, such as vinegar, dissolve lead, forming poisonous soluble salts. In the presence of air and moisture lead may corrode by the formation of a white basic carbonate (compare verdigris). The compounds of lead are of considerable commercial importance, being used in the manufacture of oils, flint glass, glaze for earthenware, and paints.

THE PRECIOUS METALS

Silver, gold, and platinum are the more valuable of the metals which figure to any marked extent in daily life. Silver and gold are employed extensively for coins, medals, jewellery, and ornamental purposes, while platinum is used for jewellery, in dentistry, and as conducting wires, enabling electricity to be conducted to

the inside of electric lamps, wireless valves, etc. Since platinum when heated expands to the same extent as glass, they cool forming a perfectly tight connection where the platinum wire passes though the glass. The lamp or wireless valve thus being air-tight the air can be pumped out, producing the necessary degree of exhaustion.

All these metals occur native, that is, as metal; gold and platinum are practically always in this form, but silver occurs mainly as a sulphide called argentite, Ag_2S. Silver is a good conductor of electricity, it is malleable, and it does not oxidise in air, though silver articles tarnish by formation of sulphide due to air contaminated by hydrogen sulphide (Chapter XXXV). British sterling silver coins contain 92·5 per cent. of silver, the remainder being copper, and standard silver plate also contains these metals in the same proportions.* So-called oxidised silver consists of silver that has been dipped in a solution of alkaline sulphide, thus by reaction coating the article with a thin layer of silver sulphide.

Gold occurs as yellow metallic grains in quartz rocks or in alluvial gravels deposited by rivers, such gravels being formed by the wear and tear of former auriferous rocks. Larger lumps or nuggets are of rarer occurrence.

Gold being very heavy, it can be separated from other material in a river gravel by agitation in water, the gold dust settling at the bottom, while the other matter is swept forwards. This process is known as **placer mining**. In the case of gold-bearing quartz rock, the material is powdered by stamper mills, and then treated with a weak solution of potassium cyanide, with the result that the gold is dissolved as a salt called gold cyanide. From this solution the metal may be obtained by electrolysis. This method of obtaining gold from auriferous quartz is known as the **cyanide process.** It may also be extracted by means of liquid chlorine since gold chloride is also soluble.

The metal is not acted upon by air or by strong acids used singly. A jeweller tests an article by adding a drop of strong

* Since the year 1920 British silver coins contain a very much higher percentage of copper, being made of one-half silver and one-half alloy, hence the colour of these more recent coins is different.

nitric acid, when, if it is gold, no reaction takes place, but should the article be composed of copper, brown fumes of nitrogen oxide are immediately evolved (Chapter XXXIX). A mixture of nitric and sulphuric acids will dissolve gold, and is known as *aqua regia*, since it dissolves the ' royal ' metal.

In standard or sterling British gold coins 91·66 of the material is gold, the rest is copper. The proportion of gold in jewellery, etc., is expressed by a unit known as a **carat.** Thus we have articles made of 22, 18, 15, 12, or 9 carat gold. In a nine carat article, only 9 parts in 24 by weight are composed of gold, but a sovereign is of 22 carat quality, only $\frac{1}{12}$ of it being copper. The number of 24ths that are gold determines the carat value or quality of the article, which should bear a ' hall mark ' indicating such quality.

Platinum is obtained mostly from gravels in the Urals and Caucasus. It is of grey colour and is harder than gold. In jewellery it is used as a mounting material in place of gold, and, on account of its being unaffected by strong acids and many other chemicals, it is of special use in the laboratory, while certain forms of platinum are valuable in some chemical industries since they act in these cases as catalysts.

Each of the three metals mentioned above has its uses in the art of **photography,** but silver compounds play a much greater part than the others, since certain silver salts are more easily affected by light. The influence of light can be demonstrated by the addition of a few drops of hydrochloric acid to a solution of silver nitrate. A white precipitate of silver chloride is formed, and this slowly becomes violet and eventually black when left exposed to light. The substance known as silver bromide acts in a similar manner and is the compound most commonly employed in the manufacture of photographic plates, films, and printing-out papers. Plates and films consist of glass or celluloid covered with an emulsion containing silver bromide. A photograph of an object is obtained because the lighter parts of it reflect more light and produce a greater effect on an exposed plate in a camera than darker parts of the object do.

When the plate or film is developed by immersion in a reducing solution, called a **developer,** it is found that varying amounts of

finely divided metallic silver construct an image or picture of the object. Since the lighter parts of the object produce the greatest effect on the plate, the picture is a **negative**, having darker parts representing lighter portions of the object and *vice versa*. Unaffected silver compound is dissolved and removed by the process called **fixing** and the negative becomes permanent. Prints are obtained on sensitive paper also containing silver compounds. The negative is placed between the light and the paper, with the result that the darker portions of the negative protect the paper more and produce the lighter parts of the picture obtained. In this way a 'positive' or illustration corresponding to the

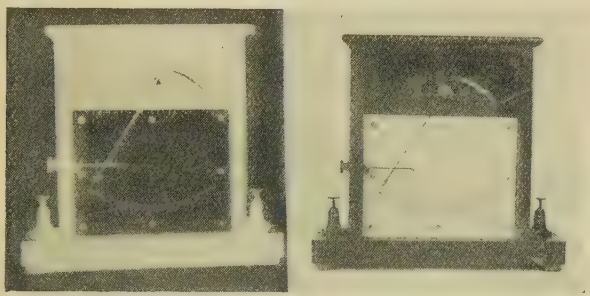


FIG. 346.—NEGATIVE (left) AND POSITIVE (right) OF A PHOTOGRAPH OF A VOLTMETER.

original object is obtained, and in order that this picture shall not be further affected by light, it must be fixed by immersion of the paper in a solution of sodium hyposulphite, commonly called 'hypo.' There are many varieties of printing-out paper, some containing silver chloride, others silver bromide, but the action of light upon them is slower than it is on plates.

Gas-light papers are those insensitive to weak diffused daylight, but affected when held at a definite distance from an artificial light. The picture obtained is not visible until the paper is 'developed.' In the platinotype process a paper containing iron and platinum compounds yields a print due to metallic platinum in place of silver, and the pictures so obtained are among the finest and most artistic results of photography. Gold is useful

for toning, that is, adding warm tints to prints, and this is accomplished by treatment with a solution of gold chloride.

ALUMINIUM AND ALUMINOTHERMY

It is quite impossible to give here an adequate account of the services of electrolysis to chemical industry, but it may be observed that by its means certain metals are extracted from their ores and many others are refined. The best known metal obtained from its ore by such a process is **aluminium.** As explained in the next chapter, the chief source of this metal is a decomposition clay known as **bauxite.** Before it can be acted

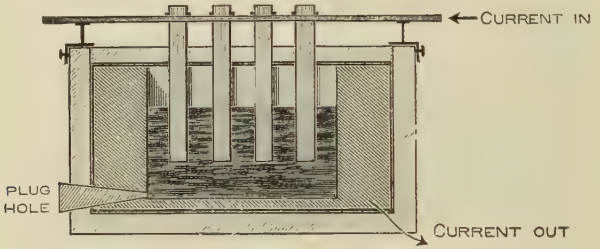


FIG. 347.—APPARATUS USED FOR THE ELECTROLYTIC EXTRACTION OF ALUMINIUM FROM BAUXITE.

upon by electricity the bauxite must be purified either by treatment with sodium carbonate or by being heated. By such means aluminium hydroxide, $Al(OH)_3$, is obtained, and this, mixed with another substance called cryolite, which acts as a flux, is put into a large rectangular iron box which constitutes the negative electrode of the electrolytic cell (Fig. 347). Many carbon rods connected electrically form the anode or positive electrode of the arrangement. When the current from a dynamo is passed through the mass, heat is generated by resistance and the mass is thus liquefied. Aluminium, which forms the positive ion, collects at the bottom and can be run off, while oxygen, which forms the negative ion, combines with the carbon of the positive electrode to give carbon monoxide.

Prior to 1850 the metal was a curiosity, but now enormous quantities are made into various domestic appliances and other

articles too numerous to be mentioned. The qualities which make it useful are its strength, its stability, and its lightness, the specific gravity being only 2·6. It is both malleable and ductile.

An important modern application is known as **aluminothermy,** a process for the development of great heat by the use of aluminium and certain metallic oxides. A mixture of powdered aluminium and iron oxide when ignited by burning magnesium develops a temperature higher than 3000°, the iron oxide being reduced by the aluminium :

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe.$$

Such a mixture, known as **thermite,** ignited upon an iron joint, causes the iron to melt and the pieces become firmly welded together (Fig. 348). Sometimes a trail of thermite is employed to cut through large pieces of iron or steel.

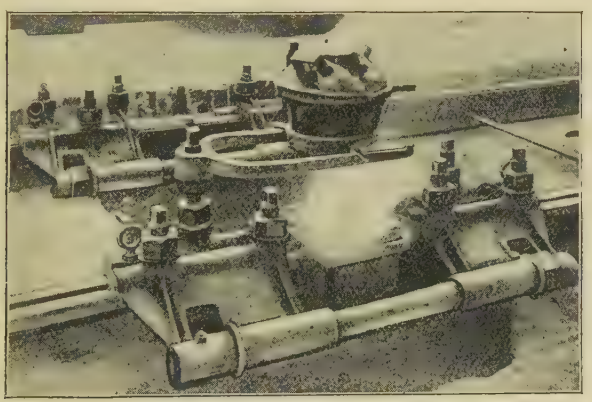


FIG. 348.—WELDING RAILS BY MEANS OF THERMITE.
MOLTEN IRON FROM THE THERMITE MIXTURE COLLECTS AT THE BOTTOM OF THE CONICAL CRUCIBLE AND IS RUN ON TO THE RAILS TO BE WELDED.

The aluminothermic process of reduction is employed to obtain the metal chromium required for the manufacture of chrome steel. Oxide of chromium is mixed with aluminium powder and placed in a large crucible composed of heat-resisting clay. Above this is a layer of sodium peroxide and aluminium powder, which is more easily started by burning magnesium

ribbon. The heat produced by the change taking place in this top layer gives the necessary ' kick-off ' to the main mass of material below. At the end of the reaction a solid lump of grey metallic chromium is found at the bottom of the crucible.

The metals manganese and tungsten can be obtained by the same process. Tungsten occurs in a mineral known as wolfram, and is used for the filaments of electric lamps because it has a very high melting point (3540°), and gives nearly three candle power with the same electrical energy as would produce only one candle power with a carbon filament. Steel containing tungsten is extremely hard and keeps its temper even when it becomes red hot, consequently it is much employed for drills and other tools. Another metal called molybdenum makes a steel even harder and more durable than that containing tungsten.

THE LIQUID METAL

The only known metal which is liquid at ordinary temperatures is **mercury,** sometimes termed quicksilver on account of its mobility and appearance. It is employed in barometers, because it is very heavy, does not evaporate easily, does not oxidise or otherwise tarnish when exposed to air, can be seen easily, and because it does not ' wet ' the containing tube.

For much the same reasons it is of use in thermometers, but in this case another important factor is its boiling point; of course, only temperatures below this can be determined by means of mercurial thermometers.

The natural ore of the metal is a beautiful vermilion coloured mineral termed **cinnabar,** which is sulphide of mercury, HgS. This mineral is of relatively rare occurrence in Europe, being found in Spain and Idria, but is more abundant in China, Mexico, Peru, etc. The extraction of the metal from its ore is one of the simplest of metallurgical operations, mere roasting in air being sufficient to oxidise the sulphur and remove it as sulphur dioxide.

$$HgS + O_2 \rightarrow SO_2 + 2Hg.$$

The mercury, which is vaporised by the heat, is condensed and collected as liquid in large chambers, or in sets of vessels.

The liquid metal acts as a solvent for some other metals, and the result is termed an **amalgam**. Thus gold dissolves in mercury, and this method is sometimes employed for gold extraction. Tin and mercury form a bright 'silvery' amalgam used for the backs of mirrors, while zinc and copper amalgams are employed in dentistry for stopping decayed teeth. Zinc plates of electric batteries are also 'amalgamated' by dipping them in mercury after they have been thoroughly cleaned; the mercury forms a protective coat which prevents the zinc dissolving in the acid except when a current is being drawn from the battery.

NOT TO BE
TAKEN FROM
THE BUILDING

CHAPTER XLI

THE CHEMISTRY OF SOME COMMON ROCKS

The earth's crust is composed of various rocks, ranging in type from soft muds to hard limestones and granites. Many of the harder kinds are useful as building material and as road 'metal,' but some are valuable on account of the kind of matter of which they are composed—they are useful for chemical reasons apart from their physical properties. The most important kinds in this respect are limestones, clays, sandstones, and related rocks.

LIMESTONES AND PRODUCTS OBTAINED FROM THEM

The chemical name for limestone is **calcium carbonate,** and its composition is expressed by the formula $CaCO_3$. A molecule of limestone consists of one atom of calcium, one of carbon, and three atoms of oxygen, all in chemical combination. In a previous chapter it was observed that carbonates are salts derived from carbonic acid, a rather weak kind of acid often consumed as a drink known as **soda water.**

Calcium carbonate is the normal calcium salt derived from this acid, and the formation of the soluble *bicarbonate*, a different substance, is described later. Pure colourless transparent calcium carbonate occurs as material filling mineral veins and is known as **Iceland spar.** This substance possesses the property of double refraction and is used for certain optical purposes.

Massive limestones occur on an enormous scale, often forming hills extending over hundreds of square miles of country. In Great Britain the chief limestone districts are the Pennine Range, the Mendip Hills in Somersetshire, the Cotswolds, the Chiltern Hills, the chalk downs of South East England, a fringe of hills

around the South Wales coalfields, the coast lands of Dorsetshire, etc.

How were these great masses of limestone formed? Nearly all of them are great accumulations of shells, corals, sea urchins, and similar structures which, some millions of years ago, formed the hard parts of creatures inhabiting ancient seas which extended at different times over parts of the country. Calcium salts in these ancient sea waters were used by the various animals to form their shells or other hard parts, and we must regard organic limestones of this kind as huge cemeteries wherein rest the remains of countless millions of creatures. These rocks represent the floors of seas that have long since vanished, many limestone hills now reaching an altitude thousands of feet above sea-level. There are other poorly fossiliferous limestones which appear to have been thrown out of solution as chemical precipitates in much the same way as calcium carbonate is precipitated when water is softened by Clarke's process (see Chapter XXXIV). Still other kinds of calcareous rock known as **marble** are produced by the action of heat upon ordinary limestone.

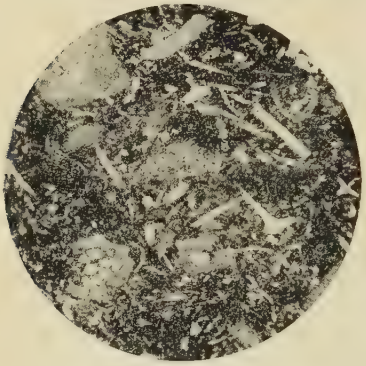


FIG. 349.—MICROSECTION OF LIMESTONE
SHOWING ORGANIC STRUCTURES—SPONGE SPICULES, POLYZOA, RADIOLARIA, ETC.
Photomicrograph by G. S. Sweeting.

THE MANUFACTURE AND USES OF LIME

When powdered limestone is placed in a porcelain crucible and strongly heated for some time, a very definite chemical change takes place, though the material remaining in the crucible is a white powder very similar in appearance to the original substance. The eye detects no change, but simple chemical tests show that a change has occurred. The original substance

brought into contact with dilute hydrochloric acid causes a brisk effervescence due to the escape of the gas called carbon dioxide, but the residue exhibits no such effervescence with acid, provided it has been heated long enough. This residue contains no carbon dioxide, hence the heat has caused the carbon dioxide to escape from the limestone into the air. What is the white residue? If a little of it is added to water, a solution is obtained in which, on blowing air from the exhaled breath through it, white particles of limestone are precipitated, making the solution turbid. This is a test for lime water, and the residue in the crucible must be **lime,** also called **calcium oxide.**

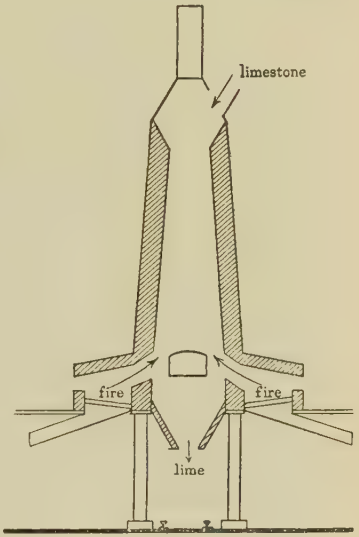


FIG. 350.
VERTICAL SECTION OF A LIME KILN OPERATED CONTINUOUSLY.

The action of heat upon limestone is expressed by the equation:

$$\underset{\text{Limestone}}{CaCO_3} \rightarrow \underset{\text{Lime}}{CaO} + \underset{\text{Carbon dioxide}}{CO_2}.$$

Lime water is more correctly termed a solution of calcium hydroxide, a substance represented by the formula $Ca(OH)_2$, and the formation of which is due to the combination of lime with water. Thus:

$$CaO + H_2O \rightarrow Ca(OH)_2.$$

Now, if carbon dioxide is passed into lime water, particles of limestone are formed:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

If an excess of carbon dioxide is added to the solution the turbidity disappears, because the soluble calcium bicarbonate is formed:

$$CaCO_3 + CO_2 + H_2O \rightarrow \underset{\text{Calcium bicarbonate}}{CaH_2(CO_3)_2}.$$

This reaction explains the solution of limestone in rain water containing carbon dioxide obtained from the atmosphere, and accounts for the formation of caves and enlarged crevices common in limestone districts (Fig. 301). The caves of Cheddar in Somersetshire afford a famous example.

With regard to the production of lime from limestone, if the respective molecular weights are given in the equation

$$CaCO_3 \rightarrow CaO + CO_2,$$
$$100 = 56 + 44$$

it is evident that every 100 parts by weight of limestone yields 56 parts of lime, provided that the limestone is pure and decomposition is complete. Most limestones are impure, so that the proportion of lime obtained is less than 56 per cent. The heating of limestone, often miscalled burning, is carried out in **kilns.** In the older type of kiln, still much used, the blocks of stone are placed in layers alternately with layers of fuel in a vertical circular tower and a fire is started at the base. All the fuel being consumed, the fire goes out and the resulting lime is extracted. In a more modern type of large kiln the fire never goes out. The kiln is in the form of an oval tunnel, and while the fire is causing decomposition at one place, the lime is being removed from an opening in the tunnel on the other side of the oval. The numerous openings, which can be closed up where necessary, enable fuel and limestone to be put in place and lime raked out, so that the fire proceeds round and round the tunnel. Some vertical kilns are fired by gas and the process is continuous (Fig. 351).

The lime obtained is often called **quicklime** and easily combines with a certain amount of water forming **slaked lime,** which is still dry and warm, since considerable heat is generated in the process. A mixture of slaked lime, which is really **calcium hydrate,** with more water and a good proportion of sand, is known as **mortar,** and is employed in building operations. The hardening of mortar is due to carbon dioxide in the air slowly combining with the calcium hydrate to form calcium carbonate, as indicated in one of the equations given above. The new particles of carbonate produced form a firm mass by intermixture with the fragments of sand.

Limestone itself is used as a **flux**, that is, as a substance which assists in the fusion of metallic ores in smelting, and when powdered and 'burnt,' limestone mixed with clay produces

FIG. 351.—A MODERN LIME PLANT,

CONSISTING OF TWO PRIEST PATENT PRODUCER GAS FIRED VERTICAL CONTINUOUS SHAFT KILNS, THE KILNS BEING CHARGED BY MEANS OF AN INCLINED AUTOMATICALLY OPERATED DOUBLE SKIP HOIST, WITH ELECTRIC AND HYDRO-ELECTRIC CONTROL AND BELL OPERATING GEAR.

EACH KILN PRODUCES MORE THAN 200 TONS OF GOOD LIME PER WEEK, ON A FUEL CONSUMPTION OF 4 CWT. OF COAL PER TON OF LIME PRODUCED.

(Reproduced by courtesy of Priest Furnaces, Limited.)

cement, which is considered to be a mixture of the two compounds, calcium silicate and calcium aluminate. The clay supplies the silicon and aluminum necessary to form these substances with the calcium in limestone. In place of clay, the slag

of blast furnaces is commonly used, since it also contains the required elements. Under the influence of water the calcium

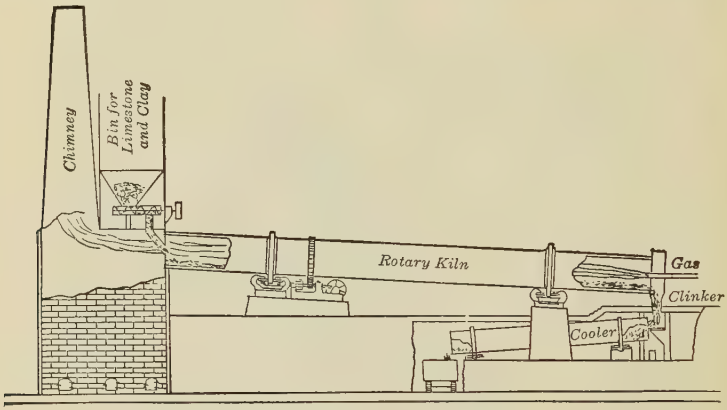


FIG. 352.—A ROTARY CEMENT FURNACE.

POWDERED LIMESTONE AND CLAY ARE THOROUGHLY MIXED AT A UNIFORMLY HIGH TEMPERATURE IN A ROTATING CYLINDER. THE PRODUCT OR CLINKER IS THEN BROKEN UP AND TREATED WITH WATER.

aluminate is converted to the hydroxides of calcium and aluminium. Thus :

$$Ca_3(AlO_3)_2 + 6H_2O = 3Ca(OH)_2 + 2Al(OH)_3.$$

Calcium aluminate + Water = Calcium hydroxide + Aluminium hydroxide

The formation of these hydroxides welds the whole mixture into a compact mass. Hydraulic cements are those particularly suitable for use under water.

SOME USES OF CARBON DIOXIDE

Lime is of importance not only in building but also in agriculture, where it is employed to improve sour soils, and the other part of limestone, carbon dioxide, is quite as important. The ordinary mode of preparing a sample of this gas in the laboratory is by the addition of dilute hydrochloric acid to pieces of limestone placed in a flask fitted with a thistle funnel and a delivery

tube. The reaction which takes place is represented by the equation :

$$CaCO_3 + \underset{\text{Hydrocholric acid}}{2HCl} \rightarrow \underset{\text{Calcium chloride}}{CaCl_2} + H_2O + CO_2.$$

The carbon dioxide liberated is soluble in water and must be collected by displacement of air as shown in Fig. 365. Experiments with the gas show that it is heavier than air, has no smell, no colour, it dissolves easily in water, and will not allow things to burn in it. The last two mentioned properties are of considerable practical importance. At a pressure about equal to 8 or 9 times that of the atmosphere considerable volumes of carbon dioxide dissolve readily in water, forming soda water and other aerated drinks. Soda water is so named because sodium carbonate is used to supply the carbon dioxide.

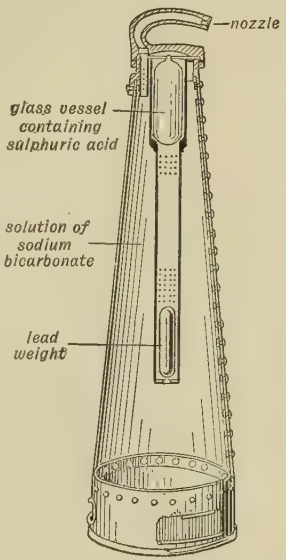


FIG. 353.—VERTICAL SECTION THROUGH A FIRE EXTINGUISHER.

WHEN THE APPARATUS IS INVERTED THE LEAD WEIGHT FALLS AND BREAKS THE GLASS VESSEL SO THAT THE ACID MIXES WITH THE CARBONATE.

(By courtesy of Messrs. Merryweather & Co.)

A **fire extinguisher** (Fig. 353) is a portable apparatus containing acid, sodium bicarbonate, and water. The glass tube which contains the acid is broken by inverting the extinguisher or, in some forms, by striking some part, thus releasing the acid in the carbonate solution; the large volumes of carbon dioxide produced force out through a nozzle a solution which extinguishes fire better than ordinary water does.

But the greatest benefit conferred by carbon dioxide upon man and other living creatures is its action as a food material for plants. Under the influence of sunlight, the **chlorophyll** or green colouring matter of leaves enables the plant to assimilate

the carbon and give the oxygen back to the atmosphere. The carbon so obtained by the plant combines with other elements to form new protoplasm, the substance of which all living things are composed. Animals cannot build protoplasm in this way, consequently they ultimately depend upon this action of chlorophyll upon carbon dioxide. The liberation of carbon dioxide during fermentation is discussed in a later chapter (XLIII).

White, solid, snow-like carbon dioxide, which evaporates at a temperature of $-79°$, is useful for producing low temperatures, and is used in some minor surgical operations, such as the removal of moles from the skin, to produce insensibility to pain.

In addition to limestone the useful naturally occurring compounds containing lime include **gypsum** or **calcium sulphate, apatite** or **calcium phosphate,** and the double carbonate of calcium and magnesium called **dolomite.** Gypsum may be clear and glassy, or white, or pink, and has resulted from the drying up of very ancient salt lakes. The purer forms are called **alabaster,** and since the mineral is very soft it is easily made into bowl fittings for electric lights, ornaments, and clocks.

Gypsum is a hydrated form of calcium sulphate, the formula of which is $CaSO_4 2H_2O$; by the application of heat the water is drawn off leaving the anhydride, $CaSO_4$. **Plaster of Paris,** used in plastering walls and ceilings, in surgery, etc., is made by driving off most but not all of the water in gypsum, the residue being a nearly dehydrated sulphate which eagerly takes up more water, forming a rigid mass.

Apatite is used both as a fertiliser for improving soils and as a source of phosphorus.

The double carbonate, dolomite, often forms massive hills and occurs mainly as an alteration product of limestone due to the influence of magnesian waters upon it. Some dolomites yield excellent material for cement and for the linings of furnaces, particularly the Bessemer converter used for the production of steel.

SAND, AND THE MANUFACTURE OF GLASS

At the present time sand collects along many a shore line as a residue formed by the wear and tear of rocks, both along the coast and inland. Extensive beds of sandstone now found in many places far from the sea are a clear indication of the former existence of an ancient shore line. A few sandstones appear to be old desert formations, but the majority are ancient shores, as shown by the shells and other fossils found in them.

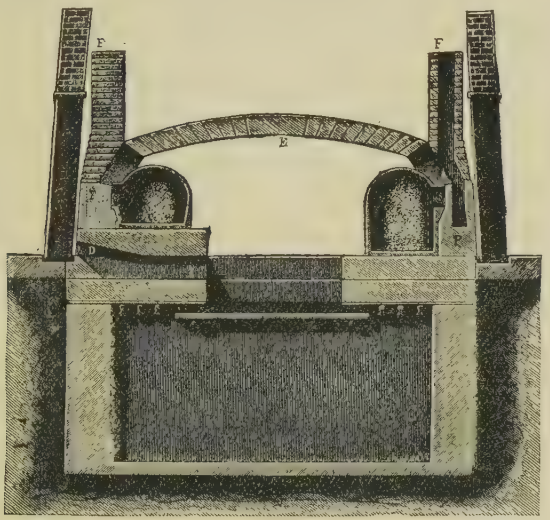


FIG. 354.—SECTION THROUGH A GLASS FURNACE.
D, FIRING HOLE; F, FLUES; E, CROWN ON WHICH FLAMES STRIKE AND SO COME DOWN AROUND FIRECLAY POTS. THESE POTS, TWO OF WHICH ARE SHOWN, ARE ARRANGED AS A CIRCLE. THE GLASS PRODUCED IS *annealed* BY VERY SLOW COOLING.

Sandstones differ considerably in their actual mineral contents, but generally the greater part of the rock is composed of worn grains of **quartz** or **oxide of silicon,** often called **silica,** a substance represented by the formula SiO_2. Though the element silicon itself is not found free or uncombined in nature, its various compounds are so common that they make up at least one quarter of the earth's crust. In addition to the oxide which occurs as enormous masses of sandstone, there are the mineral

silicates, notably the **felspars, micas, asbestos,** and many others. Silicates are compounds derived from silicic acid, just as carbonates are derived from carbonic acid. As examples of useful silicates artificially produced may be mentioned that of calcium in cement, mentioned above, and sodium silicate, commonly called **water glass,** employed for preserving eggs, for making textiles waterproof, etc.

There are many useful forms of silicon dioxide or silica. The large clear crystals of quartz known as rock crystal are employed in the manufacture of lenses for optical purposes; coloured crystals, such as the purple amethyst, rose quartz and the brown cairngorm, are used as precious stones, so also is the hydrated form of silica known as opal; while agate, chalcedony, and jasper are worked into brooches and other small ornamental articles. In most sandstones there are in addition to silica smaller proportions of various other minerals, mostly silicates, such as garnet, mica, felspar, etc. For glass making, the more easily broken sandstones containing a high proportion of pure silica are required, and in recent years a very thorough investigation of British sands for industrial purposes has been made by Prof. Boswell of Liverpool University.

Ordinary common **glass** is a complex silicate of lime and soda, and is prepared by melting together limestone, sodium carbonate, and pure sand, but the reaction which takes place may be represented by the equation:

$$\underset{\text{Limestone}}{CaCO_3} + \underset{\substack{\text{Sodium}\\\text{carbonate}}}{Na_2CO_3} + \underset{\text{Sand}}{6SiO_2} \rightarrow \underset{\text{Glass}}{CaONa_2O6SiO_2} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{2CO_2}.$$

For window glass, the materials used must be purer than those employed for the manufacture of cheap bottles, which are usually coloured by silicate of iron due to iron compounds in the limestone. Chemical apparatus is made of soft or of hard glass according to the purpose for which it is used. Tubing is made of the former, which is sometimes termed soda glass since the proportion of sodium in it is high, while heat-resisting flasks, etc., are composed of hard 'Bohemian' glass in which potassium carbonate is substituted for sodium carbonate. Flint glass, and cut glass made from it, are composed of sodium-lead silicate,

lead oxide being substituted in place of limestone. Coloured glass is produced by the addition of various oxides, which, fusing with the glass, give coloured silicates. Thus uranium produces yellow, copper oxide green and sometimes ruby, cobalt oxide blue, etc. Ordinary glass is more or less opaque to ultra-violet rays, but a quartz glass named vitaglass permits these rays

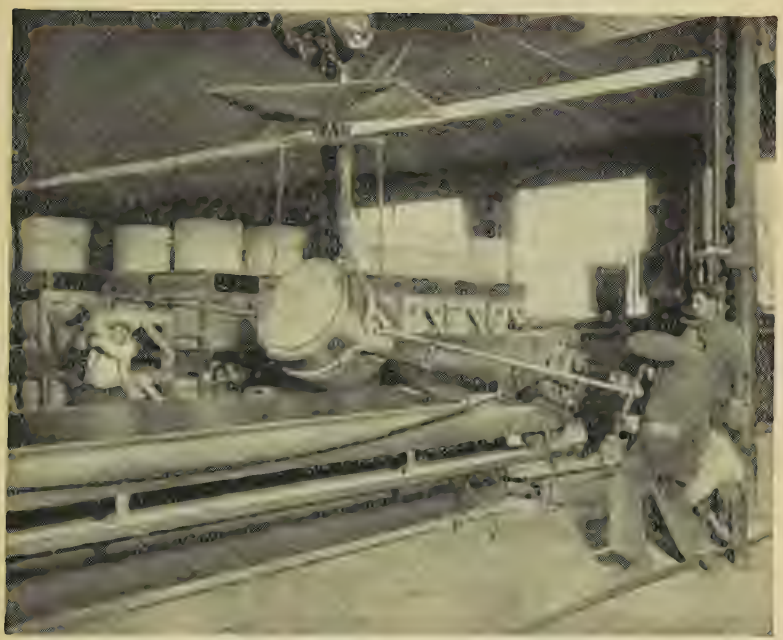


FIG. 355.—POURING AND ROLLING PLATE.
MOLTEN GLASS AT A TEMPERATURE GREATER THAN 1000° C. IS POURED ON TO HOT IRON PLATES AT A TEMPERATURE OF 500° C.

to pass through and it is now being used for hospital windows as well as in some dwelling houses. Most acids have no action on glass, but an exception is hydrofluoric acid, employed for etching patterns on glass (Chapter XXXVIII).

Glass making is of great antiquity, and it is generally believed that it may have originated in Egypt, where natural carbonate

of soda occurs. It is certain that glass was employed extensively by the Romans for domestic purposes, and in England it was manufactured during the Roman occupation. In modern times the most advanced processes of glass manufacture were carried on mostly at Jena in Germany, but high quality glass for optical purposes is now also manufactured in England.

CLAYS AND EARTHENWARE

The plastic rocks termed clay are of very widespread occurrence and of varied origin. Most of them were deposited below the sea and contain marine fossils, but many of the more useful clays are of fresh water and estuarine origin; those of the coal measures are of this type. Other varieties have resulted from the chemical alteration of mineral substances, particularly the felspars in granite and in basalt, by the influence of rain water and carbon dioxide. In colour, clays differ considerably, ranging from white to dark grey, while yellow and red tints, due to the presence of iron compounds as impurities, are of common occurrence.

All kinds of this rock consist essentially of water, aluminium oxide, and silica combined together, producing a **hydrated silicate of alumina,** hence the formula for clay may be written

$$H_2O,Al_2O_36SiO_2,$$

or the compound may be regarded as a salt of a silicic acid, $2HAlSi_3O_8$. Clay being plastic, it can be moulded to desired shapes, and when heated the residue is a hard non-plastic silicate termed earthenware. The manufacture of pottery is probably the oldest of chemical industries, since neolithic man, that is, man of the later stone age, certainly knew how to make earthenware vessels.

The purest clay employed for the making of the finest china ware is the fine white **kaolin,** found in granite areas and mined extensively in Cornwall (Fig. 356). One of the chief constituents of granite is orthoclase, a potash felspar having the composition $2KAlSi_3O_8$. If this combination be stated as a combination of potash, aluminium oxide, and silica, the

influence of rain water and carbonic acid upon felspar can be expressed clearly :

$$\underset{\text{Unaltered felspar}}{K_2OAl_2O_36SiO_2} + CO_2 + H_2O \rightarrow \underset{\text{Kaolin}}{H_2OAl_2O_36SiO_2} + \underset{\text{Potassium carbonate}}{K_2CO_3}$$

Water takes the place of potash, which combines with the carbon dioxide to produce potassium carbonate, and this being soluble,

FIG. 356.—A CORNISH KAOLIN PIT.
(By courtesy of the Director, Geological Survey of England and Wales.)

is removed in the rain water. The process is a slow one ; many granite masses still remain unaltered and the kaolin deposits of Cornwall and elsewhere are probably the result of slow chemical action extending through some millions of years.

In the manufacture of china articles the material is heated several times. After the first heating it is porous and the pores have to be filled in. This is done by coating the articles with a fine paste composed of ground felspar and silica, which on the second heating fuses and occupies the pores. Ornamental coloured patterns are produced by adding various metallic

oxides which fuse, yielding coloured silicates when the material is again heated.

The common impure clays, such as those found in the various coalfields, are employed in the manufacture of bricks, tiles, and less valuable forms of pottery. The red and yellow colours of bricks are due to iron oxide, which is present as a natural impurity in these clays. White porcelain can be made from the more common clays, provided the iron oxide is first removed. This is now accomplished by the **Schwerin process**. The clay

FIG. 357.—POTTERY—A THROWER.
(By courtesy of Messrs. Doulton & Co., Ltd.)

is thoroughly mixed with water, thus forming a ' suspension ' in which the minute particles, although not dissolved, are well distributed throughout the liquid. A large plate connected to the negative pole of a dynamo is then placed in the suspension ; this attracts all the iron oxide to one side of the containing trough, while pure clay is obtained near another plate connected to the positive pole of the dynamo.

Since all clays contain aluminium, it is not surprising that rocks of this class provide the usual sources of this metal, but all clays are not equally valuable in this respect. The best source

of aluminium is a clay called **bauxite,** which is a decomposition product of plagioclase felspar in much the same way as kaolin is a similar product obtained from orthoclase felspar. Plagioclase contains soda and lime in place of potash, and is found in volcanic rocks like basalt. Water and carbon dioxide react with the soda and lime, carbonates are formed, and the residue consists of dark brown or red clays from which the aluminium is extracted by electrolysis as has been described in the preceding chapter.

MINERAL PROSPECTING

Since rocks and minerals are of such practical importance, a knowledge of the general properties of a great variety of mineral substances is indispensable to the **prospector,** whose business it is to recognise and identify them. Rocks are generally much more extensive but offer less numerous types than mineral ores do, and usually they are much more easily recognised. A drop of hydrochloric acid will give evidence of a limestone even when the colour may be deceptive. Clays and sandstones are easily recognised by their texture, the former by their plastic and unstratified nature, the latter by the mass of hard quartz grains composing them.

With minerals, however, of which there are a great number of economic value, the case is different. A competent mineralogist can generally recognise a specimen straight away from certain characteristics seen in hand specimens, but sometimes tests must be applied later in the laboratory.

The chief characteristic features that guide the prospector in his diagnosis are—form, hardness, cleavage, lustre, and to some extent colour, and specific gravity.

By the **form** of a mineral is meant its shape. Some occur as definite crystals, in which case a knowledge of the particular crystal shapes assumed by certain minerals is necessary. Other minerals are massive, that is, they occur in large masses not having a definite crystal outline, and some minerals may occur either as crystals or massive.

As examples of crystallised minerals, cassiterite, the chief ore of tin, and copper pyrites may be quoted. Cassiterite occurs in

well-defined tetragonal prisms capped by a pyramid, while copper pyrites crystals assume shapes called tetragonal sphenoids, which are wedge-shaped forms resembling the cubic tetrahedron.

Examples of massive minerals are clay ironstone found in irregular rounded lumps and some varieties of copper pyrites. The latter is a mineral which may be massive or crystallised.

In some cases massive minerals may assume shapes which are not crystal outlines but are nevertheless of characteristic form, and therefore of value in determination. Thus haematite or red iron ore is often found in kidney-shaped nodules, hence the name kidney iron ore.

A prospector seldom relies upon any one characteristic, but is usually led to his conclusion by a combination of features. The property called **hardness** is of particular value, and a scheme of hardness known as **Mohs' scale** is employed. In this scale the softest known mineral called talc is taken as unity, while diamond at the other end is called 10. A mineral such as emery, having a hardness of 9, is very nearly as hard as diamond. Many useful minerals are just too hard to be scratched with the blade of an average pocket knife. As an example of the use of the hardness test, the two minerals iron pyrites and copper pyrites may be taken. Often both of these occur in massive lumps of a brassy yellow colour and look very much alike, but the copper ore can be scratched with a knife blade, while that of iron cannot be so scratched.

Some minerals, such as alabaster, are so soft that they can be marked by one's finger nail.

Cleavage, or the tendency of some minerals to split along planes of weakness, is sometimes a very useful feature. For example, cleavage is so pronounced in mica that it can be split quite easily into very thin flat sheets, but, on the other hand, quartz or rock crystal used for optical lenses has no cleavage at all.

The property known as **lustre** depends upon the manner in which a mineral reflects light. Substances like quartz and mica have a bright glassy lustre, others such, as the important mineral sulphides of lead, iron, and copper, have a distinct metallic or metalloid lustre similar to that of polished metal. Other sub-

stances, for example, clay ironstone and earthy haematite, have no lustre at all, they appear ' earthy.'

Colour is a very unreliable property as a rule, though at times it is of use. Cinnabar, or mercury ore, has a very characteristic vermilion tint; useful copper sulphides are generally the colour of brass; and galena, the ore of lead, is a dark grey. On the other hand, limestone may be almost any colour from pure white, as in chalk, to black. Quite frequently iron oxide impurities give yellow and red tints to limestone, so that in the case of this mineral, colour is of no special use in diagnosis. **Specific gravity** is occasionally of use when two minerals closely resemble each other in outward appearance, but have different relative weights. By this means dolomite, of value for the linings of some blast furnaces, can be distinguished from ordinary limestone, which has a slightly lower specific gravity.

When a mineral cannot be identified in the field, its nature can usually be determined by analysis in a laboratory. In this treatment the blowpipe plays a prominent part, since many ores are reduced, leaving a fragment of metal when heated on charcoal in the blowpipe flame. In other cases coloured residues left on the charcoal give some indication of the nature of the original material. Other laboratory tests include the use of the microscope, and examination by means of reactions with various dry and wet chemicals.

CHAPTER XLII

CARBON, COAL, AND COAL GAS

Smoked glass can be made by repeatedly holding it momentarily in the upper part of a candle flame, so that it becomes coated with particles of black carbon. The carbon is a constituent of the candle wax and its deposit on the glass is due to incomplete combustion of the molten wax in the wick. Soot from a chimney, and lamp black, are similar deposits of amorphous or non-crystallised **carbon**, the latter being liberated freely from oil by a badly trimmed lamp wick, or a wick that is turned too high. **Lamp black** is of considerable use, being employed in the manufacture of ink, boot and shoe polishes, and black paint.

Another useful form of carbon known as **wood charcoal** is formed when wood is heated in such a way that air does not get to it, and it cannot burn. If a few wooden shavings are put into a glass test-tube, and heated over a bunsen flame, certain vapours and gases escape from the wood, ultimately leaving a black solid residue of charcoal.

Wood consists, then, of charcoal or carbon combined with certain volatile substances which can be expelled by heat. These volatile constituents are of a complex character, and include wood gas, which can be burned if the tube is fitted with a jet, and certain liquids—water, tar, and wood spirit—which condense on the upper cooler end of the tube. When sugar is heated in a similar manner it first turns brown, gives off vapours, and finally leaves a black carbon residue. Both the wood and the sugar originally formed part of a living plant, each entered into the composition of an organism. The framework of animals also contains compounds of carbon, as can be demonstrated by the

heating of bones in a closed tube, when **animal** or **bone charcoal** is obtained. For this reason the study of the carbon compounds is known as **organic chemistry,** but the term now includes the study of many substances, such as chloroform, which contains carbon and can be prepared in the laboratory without having formed part of a living organism. Though many organic compounds can be prepared artificially, carbon is one of the most widespread substances in nature.

Every plant and every animal that exists contains this element, and every organism that has lived in bygone times was largely made of carbon. Some of the oldest rocks in the world contain beds of black **graphite,** a form of carbon that may once have been part of a living organism. The slow processes of nature have taken millions of years to produce a carbonised residue very similar to that which can be produced in a few minutes in a laboratory.

There can be little doubt that many graphite beds are due to the slow escape of volatile constituents from early forms of plant life. Coal is of a somewhat similar origin, and more will be said of this later.

Now, what are the properties of this element called carbon? It is solid at all temperatures except those above 3600°, and at this high temperature, and under ordinary atmospheric pressure, it becomes gaseous without passing through an intervening liquid form. Charcoal is heavier than water, its specific gravity being about 1·5, though a piece floats on water because it contains innumerable pores filled with air.

Since carbon resists heat so well and is a good conductor of electricity, it is employed in electric arc lamps and furnaces, also as an electrode in certain applications of electrolysis.

On account of its porous nature, fresh charcoal absorbs large quantities of gas, hence it is used as a means of purifying sewers, etc. For the same reason charcoal biscuits are valuable in cases of flatulence. Its powers of gas absorption are illustrated by the fact that at 0° C. one cubic foot of charcoal will absorb about 68 cubic feet of carbon dioxide or 170 cubic feet of ammonia. Liquids and solids are also absorbed, hence carbon is used to remove the brown colouring matter of sugar, rendering it more

fit for use on the tea table, and water may be purified by its absorption of bacteria and other impurities.

Carbon burns in air, forming carbon dioxide, but in cases where the oxygen supply is more limited carbon monoxide is produced. This tendency to form the monoxide is particularly valuable in the smelting of metallic ores, which are consequently mixed with a form of carbon, such as coke, and heated (see Chapter XL).

Carbon is very insoluble in ordinary solvents, water, acids, etc., though it dissolves in molten iron, forming steel.

Graphite, miscalled **plumbago** because it marks paper and was formerly supposed to contain lead, is a somewhat heavier kind of carbon than lamp black or charcoal, its specific gravity varying between 2 and 3. The more useful forms of it possess a crystalline texture, and in this it again differs from amorphous or non-crystalline charcoal. Large quantities of graphite, obtained from Ceylon, Siberia, the United States, and elsewhere, are employed for many purposes, including the manufacture of so-called lead pencils, electric furnaces, crucibles, electrically conducting surfaces for electrotypes, polishing powders, and the carbon plates of batteries. The graphite mines of Borrowdale in the English Lake District are practically worked out, but in addition to the natural deposit found in these districts, the substance is made artificially by means of the electric furnace, and it occurs in blast furnaces used for iron smelting.

DIAMONDS

Graphite is by no means all pure carbon; there are varying quantities of volatile and mineral matter present, the latter forming ash when the material is burned. The better graphites contain nearly 90 per cent. of carbon, the rest being mostly ash with about one per cent. of volatile matter.

Diamond is a much purer form of carbon which yields only 0·05 per cent. of ash on being burned. The product of the combustion is carbon dioxide, proving that diamond is really carbon. There are less pure types of diamond called **boart** and **carbonado,** and these on burning may have as much as 4 per cent. of ash. The

colours of these kinds is also different from that of the more valuable diamonds, the latter being almost colourless or of a very faint yellow tint, while the former are darker and sometimes yield black diamonds.

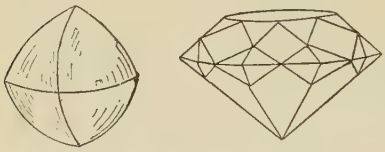


FIG. 358.—CRYSTAL AND CUT DIAMOND.

All varieties of diamond possess a crystalline structure, but the apparent highly crystalline shape of commercial diamonds is not really the result of crystal symmetry, but is due to the art of the lapidary, who cuts numerous **facets** which enable the material to make the most of its refractive powers. Light passing through the diamond is highly refracted so that it produces scintillations and play of colours, and the arrangement of the artificial facets assists considerably in producing good results. Of the shapes imparted to diamond by the cutter, *rose*, *table*, and *brilliant*, the most popular, but most wasteful, is the last named. Diamonds are found more or less rounded, or irregular in shape, though they possess true internal crystalline structure, as found in crystals of the cubic system.

The commercial value of a diamond is expressed in units called **carats**, which, of course, have a significance quite different from that of the carat employed in connection with different qualities of gold (Chapter XL). The diamond carat is a weight equivalent to 3 grains troy weight. The largest diamond yet found is the *Cullinan*, found in South Africa, and originally weighing $3025\frac{3}{4}$ carats, or more than twenty ounces, but later cut into several pieces.

In South Africa the industry commenced in the year 1867, when a stone used by a child as a plaything was identified as a diamond. Two years later a rush to the Orange and Vaal rivers took place, and in 1871 the great mining centre of Kimberley was merely a canvas camp. At this locality the diamonds are found in a bluish rock or ' ground ' composed of altered volcanic breccia occupying deep pipes, in form very similar to old choked volcanic ducts generally known as ' necks.' Diamonds were

first obtained from Brazil in 1725, and prior to that date all stones were obtained from India.

Though the finer diamonds ' of the first water ' are used as jewels, the poorer qualities, boart and waste pieces, are employed as abrasives, or substances for cutting and grinding other stones, since diamond is the hardest substance known. The name diamond is related to the word ' adamant,' which is derived from Greek and means ' that which cannot be conquered,' and refers to the unparalleled hardness of the stone.

How have diamonds been formed ? A possible answer to this question may be obtained from observation on the mode of occurrence of diamond in nature, and certain experimental work, particularly that of **M. Moissan**, a French chemist, is suggestive, though rather inconclusive.

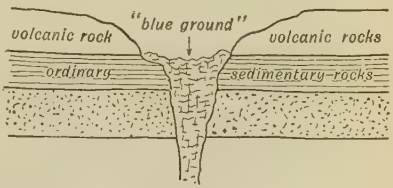


FIG. 359.

GEOLOGICAL SECTION ILLUSTRATING THE MODE OF OCCURRENCE OF DIAMONDS AT KIMBERLEY, S. AFRICA.

Diamonds are found in rocks of igneous and metamorphic origin. In South Africa they occur in volcanic material, which is now a soft blue rock, but was originally a hard compact mass. In other parts of the world, India and Brazil, diamonds occur in hard altered sandstones or in rocks called schists. It is believed that crystalline carbon was formed in these rocks as they cooled under great pressure, and experimental work shows that this may have been the case.

Though carbon at a temperature of 3600° and under atmospheric pressure passes straight from the vapour stage to the solid condition on cooling, Moissan considered that if the pressure were much greater, carbon might occur as a liquid, from which it would crystallise as diamond on cooling. He melted pure iron in a carbon crucible and some of the carbon was absorbed by the iron. When the temperature of the molten mass approached 4000°, he plunged the crucible and its contents into cold water. The sudden cooling and contraction exerted an enormous pressure, and later, when the solid iron was dissolved in acid, very small

fragments resembling diamond and boart were obtained, but the view now generally held is that they were not really diamonds. Ruby and other precious stones have been produced artificially, but the fragments obtained are minute and not of much use commercially, and the process is too costly.

COAL, ITS ORIGIN, AND USES

Fossilised fern leaves and branches and roots of trees found in coal show that it is of vegetable origin. Ancient forests sank

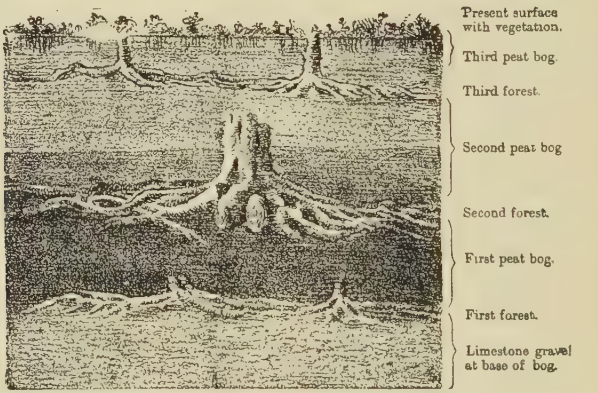


Fig. 360.—Section of an Irish Peat Moss.

beneath the surfaces of lakes, or the trees drifted down streams and were covered with silt in former estuaries. The subsidence and drift theories are mentioned in Chapter III, and here we are more concerned with the types of coal produced by various chemical changes that slowly took place in the vegetable matter after it had been buried under deposits of clay or sand, which are now found as stratified rocks above and below coal seams in mines.

The volatile constituents originally present in the large reed-like plants which lived during the Carboniferous and other periods have partly escaped, leaving a carbonised residue containing some incombustible mineral matter, which constitutes the ash found in a fire grate. But some of the volatile substances are

retained, and the proportion of these vary, being greatest in **peat** and least in **anthracite,** the latter being a coal which has been subjected to further alteration by heat and pressure. In other words, anthracite consists almost entirely of carbon and is a metamorphosed coal.

The South Wales coalfield, the only place where anthracite occurs in Great Britain, is divisible into two distinct portions, the line of demarcation being a fault running along the vale of Neath. Anthracite occurs only to the west of this line, in a region which has in the past been much disturbed and faulted by earth movements, which are believed to have been responsible for the conversion of ordinary coal into anthracite. Some kinds of household coal contains more volatile matter than others, and a different variety of fuel, rich in volatile constituents and called **cannel coal,** is particularly suitable for the manufacture of coal gas.

The table below gives an idea of the average composition of various fuels ranging from wood to anthracite.*

	Percentage of carbon.	Percentage of volatile matter *including moisture.*	Percentage of mineral ash.
Wood - - -	25	73	2
Peat - - -	29	70	1
Lignite - - -	43	49	8
Cannel coal - -	58	40	2
Household coal -	63	33	4
Steam coal - -	82	15	3
Anthracite - -	87	8	5

The vegetable nature of peat is obvious, and it occurs mainly in boggy places, as in Ireland and on Exmoor, and in alluvial tracts like parts of the vale of Somerset. It is cut in much the same way as turf is, and piled in stacks ; as a fuel its value is not great, as it contains too much earthy matter, and not enough carbon. By submitting peat to very great pressure it has been converted to a black substance resembling coal, and this emphasises the fact that the pressure of superincumbent rocks must have played a considerable part in the formation of coal.

* In this table the carbon percentages appear lower than in most similar tables because the moisture is included.

Lignite, or brown coal, is intermediate between peat and the true bituminous coals. In England lignite is of rare occurrence, deposits of it being found in certain beds of tertiary rocks at Bovey Tracey in Devonshire. Larger amounts of it occur in other young rocks in Western Germany.

Though the greater portion of the coal supplies of the world are obtained from ancient rocks of the Carboniferous formation, it must not be imagined that no other rocks yield coal. Some Mesozoic strata, for example certain oolites in

Fig. 361.—Mining Coal by Machinery.

Yorkshire, contain coal seams, and even later Tertiary rocks sometimes contain black as well as brown coals.

Steam coal, having a high proportion of carbon, burns with very little smoke, hence is of particular value in the case of warships, where a track of smoke is undesirable. This type of coal is extensively mined in the South Wales coalfield.

In both wood and peat the proportion of moisture is high, approaching 20 per cent., but in the varieties of black coal, the volatile matter is mostly in the form of compounds consisting of hydrogen and carbon only, and termed **hydrocarbons.** A typical example of a gaseous hydrocarbon is *methane*, or marsh

gas, CH_4, so called because it is formed by decomposing vegetable matter in marshy places. Inflammable natural gas issuing from borings or ' wells ' in the oil district of Baku near the Caspian Sea contains more than 93 per cent. of methane, and was burnt there for hundreds of years in the temple of the fire worshippers.

Methane is called firedamp by miners, and a mixture of it with air is responsible for most of the serious explosions in coal mines. Another gaseous hydrocarbon which burns with a luminous smoky flame is *ethylene*, C_2H_4, small quantities of which are also sometimes present in coal mines ; it forms with air an even more explosive mixture than methane does. Miners work in sets or shifts, eight hours at a time. Both before and during any shift the workings of the mine are tested for inflammable gas by officials called *deputies*. A safety lamp, burning oil and locked, is taken from place to place, and should any gas be found, it passes through the wire gauze into the lamp and burns there, though the flame cannot pass to the outside of the lamp and explode the external mixture (see Chapter XX). The deputies make a written report after each examination.

ILLUMINATION BY COAL GAS

During the seventeenth century it was known that coal contained inflammable gaseous substances, but it was not until 1792 that any serious practical consideration was given to the subject. At that date **W. Murdock** experimented with coal gas, and in 1802 he succeeded in using it to illuminate an engineering works near Birmingham. But the first public street lighting by gas was achieved in 1807, by a German named **Winsor,** who placed gas lights along Pall Mall, and within ten years from that date street lighting by gas became quite common in London. The earlier chartered Gas Light and Coke Company of London was founded in 1810. The next great step in gas illumination came many years after, towards the end of the nineteenth century, when the incandescent mantle, consisting of cotton fabric treated with thorium, was invented (see page 505). This new type of burner gave six times as much light as the old burner in consuming an equal quantity of gas.

Coal gas is a mixture consisting chiefly of hydrogen, methane, ethylene, and other hydrocarbons, with some nitrogen and carbon monoxide. All of these with the exception of nitrogen are inflammable, and the luminous nature of the coal gas flame is due principally to ethylene and acetylene. In modern times the heating capacity of coal gas is of more importance than its illuminating powers, gas illumination now being produced by rendering incandescent mantles white hot. Though a consumer still pays for his gas by the cubic foot, the actual basis of value is the heat unit called a therm (see Chapter XVIII).

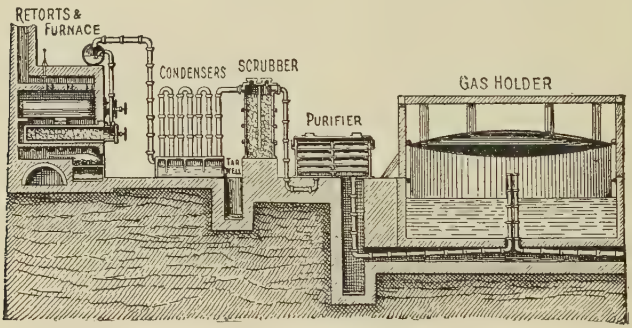


FIG. 362.
DIAGRAM REPRESENTING THE MANUFACTURE OF COAL GAS.

The composition and quality of the gas vary with the nature of the coal and the temperature conditions under which the gas is manufactured, average coal gas containing hydrogen about 49 per cent., methane 35, ethylene 4, nitrogen 4, and carbon monoxide 4 per cent., while the remainder is composed of hydrogen sulphide, carbon dioxide and other impurities, which are removed before the gas is used.

A visit to a gas works affords much interesting instruction, not only concerning the gas itself, but also about the important by-products obtained—**tar, ammonium salts, coke,** and **sulphur.** The chief parts of the gas manufacturing plant are the retorts, the condenser, the scrubbers, the purifier, and the gasholder (Fig. 362).

Cannel coal, so called because it burns in open air with a smoky flame similar to that of a badly trimmed candle, is placed

in a series of fire clay retorts arranged in tiers one row above another and heated by a furnace. Each retort is connected by a pipe to a large horizontal pipe called the *hydraulic main*, which passes the gases on to the condenser. This consists of very long iron pipes in which the gas proceeding forwards is cooled, so that gas tar and ammoniacal liquor condense here, the tar collecting below the other liquid. In the next apparatus, the *scrubber*, the gas is washed by water trickling down a tower containing coke. By this means it is cleansed of any remaining ammonium salts, tar, and some carbon dioxide, hence the name scrubber. Coal usually contains sulphur compounds, so that gases containing sulphur, hydrogen sulphide, H_2S, and carbon disulphide, CS_2, are produced by its distillation; consequently these must be removed, and the gas rendered more fit for domestic purposes by means of the *purifier*. This consists of tanks fitted with horizontal shelves supporting layers of iron oxide, which combines with the sulphur compounds and any further carbon dioxide which may have come along. Lastly, the purified gas passes through a large meter and is collected in great iron structures called gasholders. Each gasholder is a cylindrical tank placed over water, and its weight can be adjusted to ensure the pressure necessary to force the gas along the mains to the consumers.

FIG. 363.—SPRAYING TAR ON ROADS.

What happens to the various by-products? The rough carbonised residue in the retorts is called coke, a substance of considerable use as a cheap fuel and as a reducing agent employed in the smelting of metallic ores. In time a layer of **gas carbon** collects on the inside of the retorts, and this is used for the positive plates of electric batteries and other electrical purposes where carbon rods are required. Tar is a mixture of several compounds, and by its distillation are obtained many useful

substances, including **carbolic acid, naphthalene,** (both disinfectants), **benzene, creosote, various dyes,** and **oils.** Tar itself is used for preserving timber, or stonework, and for tar macadamising roads. Pitch, from which asphalt is made, is the residue left in the retorts when tar is distilled. Natural asphalt from Trinidad is a similar solid hydrocarbon.

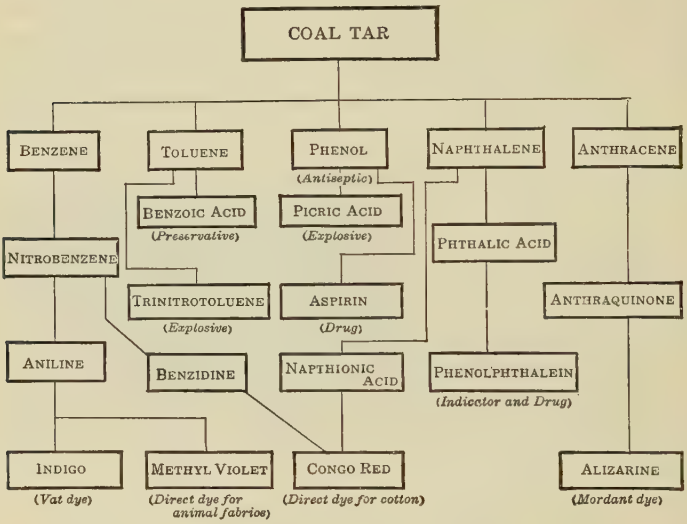


FIG. 364.
SOME OF THE PRODUCTS OBTAINED FROM COAL TAR.

The ammoniacal liquor is a source of ammonium sulphate, which as we have seen is a valuable fertiliser, and sulphur is extracted from the lime compounds formed in the purifier.

The hydrocarbons constitute several series of interesting compounds, and as there are many more of considerable practical importance, further consideration of the group is given in the next chapter.

PRODUCER GAS AND WATER GAS

Nearly all chemical reactions are accompanied either by the giving out of heat, when they are said to be **exothermal,** or by the absorption of heat as in **endothermal** reactions.

It is part of the business of a chemical engineer to study not only the quantity of heat available from the combustion of various kinds of fuel, but the relative suitability of different fuels. The oxidation of carbon will serve as an example, showing the heat results which may be obtained from chemical reaction of this kind.

When carbon is burned in an excess of air, the dioxide is formed, and though this is useful in many ways, such as the manufacture of aerated drinks, it is incombustible, and is of no further use so far as heat generation is concerned. Solid fuels such as carbon are not always convenient as they must be burned in a suitable furnace situated at a particular place.

The very poisonous gas carbon monoxide is different, as it can be burned at any desired place and yield a large quantity of heat capable of doing work of some kind, such as the heating of limestone in some form of lime kiln.

Coke is partially oxidised to carbon monoxide in a special furnace called a **producer,** and the gas obtained, carbon monoxide diluted with nitrogen, is known as **producer gas.** When a pound of carbon is oxidised in this fashion and the resulting gas is burned, more than 8000 calories of heat are obtained.

If steam is blown through a producer, a gaseous mixture of hydrogen and carbon monoxide is obtained, $C + H_2O \rightarrow CO + H_2$. Such a mixture, known as **water gas,** develops a great amount of heat by its combustion, more than three times the amount of heat resulting from the combustion of an equal volume of producer gas.

Both producer gas and water gas are extensively employed in factories, steel works, etc., since they give a steady heat and the plants require no special stoking.

There are other oxides of carbon but they are relatively unimportant. The monoxide and dioxide are often prepared in the laboratory in order that their physical and chemical properties may be studied. The monoxide, CO, is generally obtained by heating a mixture of oxalic and sulphuric acids, though it is the decomposition of the former that yields the carbon monoxide, the sulphuric acid merely removing the constituents of water :

$$\underset{\text{Oxalic acid}}{H_2C_2O_4} \rightarrow CO + CO_2 + H_2O.$$

The carbon dioxide produced at the same time is removed by passing the gases through some caustic potash, KOH, so that potassium carbonate is formed :

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O.$$

Carbon monoxide is colourless, burns with a characteristic blue flame, and is very poisonous, even small quantities producing bad headaches. It is inadvisable to breathe the air just above a coke fire.

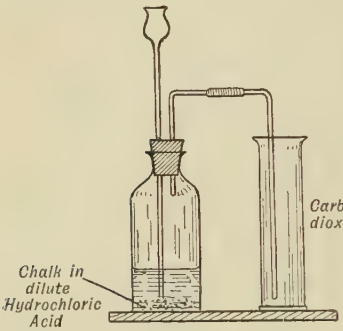


FIG. 365.
THE PREPARATION AND COLLECTION OF CARBON DIOXIDE.

Carbon dioxide, CO_2, the practical importance of which has been mentioned previously, is usually prepared in the laboratory by adding dilute hydrochloric acid to lumps of limestone placed in a flask fitted with a delivery tube, the apparatus being similar to that employed for the generation of hydrogen (Fig. 365). The carbon dioxide is expelled from the limestone, and calcium chloride, which dissolves in the solution, is formed :

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O.$$

Since carbon dioxide is soluble in water, it must be collected in jars by the displacement of air, the heavy carbon dioxide pushing the air upwards. A lighted taper plunged into the gas goes out, showing that carbon dioxide does not support combustion, neither does it burn itself. With lime water it reacts, forming particles of limestone, causing the solution to become turbid. A solution of carbon dioxide in water has weak acid properties, as shown by its action on litmus, which assumes a wine red colour.

CARBORUNDUM

With oxygen, carbon forms oxides; with hydrogen, hydrocarbons; and with certain other elements it forms compounds

called **carbides.** Calcium carbide, employed for the generation of acetylene gas, has already been mentioned, and another most useful compound of this class is known as **carborundum.** This is dark grey lustrous carbide of silicon, SiC, and is extremely hard, rivalling corundum or emery (aluminium oxide) in this respect. In the scale of hardness these substances come next to diamond. Carborundum is employed for the manufacture of grinding wheels and abrasive purposes generally, and is made by heating

FIG. 366.—ELECTRIC FURNACE
FOR THE MANUFACTURE OF CARBORUNDUM.

a mixture of sand and coke in an electric furnace having a temperature of about 3500° :

$$SiO_2 + 3C \rightarrow 2CO + SiC.$$
$$60 \quad 36 = 56 \quad 40$$

This simple reaction affords another easy example from which simple calculations can be made.

Thus, calculate the amount of carborundum obtained from one hundredweight of sand mixed with the necessary amount of coke. Where electric power is cheap, as at Niagara Falls in North America, great quantities of carborundum are made annually.

CHAPTER XLIII

OTHER IMPORTANT CARBON COMPOUNDS

PETROLEUM

CERTAIN porous rocks widely distributed in the United States of America, Mexico, Caucasia, Galicia, Burma, Japan, and elsewhere, yield a greenish yellow mineral oil commonly called **petroleum** (Latin *petra*, rock, *oleum*, oil).

The world's annual supply of this valuable commodity runs into several hundreds of millions of gallons. On a relatively small scale mineral oil occurs in Central Scotland in certain laminated rocks of Carboniferous Age, called **oil shales,** and by heating the shale in closed vessels the oil vaporises and can be condensed to liquid in a cooled receiver. A ton of shale may yield as much as 50 gallons of oil.

The origin of petroleum is a matter about which there is still much discussion. The theory most commonly favoured suggests that the oil results from the decomposition of vegetable or animal matter buried in the oil-bearing strata. Another explanation offered is that the oil results from the decomposition of metallic carbides by the action of water. It is quite probable that some cases are best explained by the first theory and that other cases are correctly interpreted by the second.

Petroleum is generally associated with natural inflammable gas, both existing some distance below the ground under the pressure of overlying rocks. When a boring is made, the pressure of the imprisoned gas forces the oil to the surface. This proceeds for such time as the gas, or perhaps the hydrostatic level of the oil itself, exerts sufficient pressure, but eventually the oil is pumped to the surface. In some cases oil gushes from natural

orifices without rendering necessary the sinking of a boring or artificial ' well.'

The crude petroleum, a viscous liquid which varies in colour from pale yellow to nearly black, is a mixture of hydrocarbons, and such mineral oil must be distinguished from vegetable and animal oils, which are generally acids or compounds of organic acids and salts known as esters. As was observed in the previous chapter, hydrocarbons consist of hydrogen and carbon only, but in different hydrocarbons the relative proportion of the

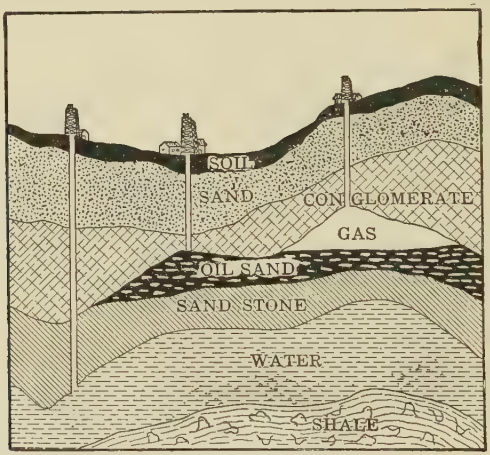


FIG. 367.
GEOLOGICAL SECTION OF OIL BEARING STRATA.

two elements vary greatly, though conforming to the law of multiple proportions. This variation in proportion or number of atoms is not a haphazard affair, but follows a definite orderly arrangement which may be illustrated by reference to the members of the **paraffin series**, a group of hydrocarbons so called because paraffin is composed of certain members of this particular group.

The simpler members of this series with their respective formulae are: methane CH_4, ethane C_2H_6, propane C_3H_8, butane C_4H_{10}, and pentane C_5H_{12}.

In this series there are many other compounds, but those just

quoted are sufficient to show that in any member of the series the number of hydrogen atoms is equal to twice the number of carbon atoms plus two. Hence C_nH_{2n+2} can be used as a general formula for the series, which is therefore known as a **homologous series.**

Some idea of the extent of this series may be obtained from the fact that solid paraffin wax contains members ranging from $C_{22}H_{46}$ to $C_{28}H_{58}$. The hydrocarbons having large numbers of atoms are commonly solid at ordinary temperatures, intermediate members are liquid, and, as in the case of marsh gas, those with a small number of atoms are generally gaseous. Obviously, petroleum is a mixture of liquid hydrocarbons with dissolved solids, and though crude petroleum is used as a fuel for locomotives, steamships, etc., many valuable substances are obtained by the simple process of splitting the crude oil up into its chief components. Now, this separation of hydrocarbons is a relatively easy matter, for the simple reason that the various substances boil at different temperatures. Hence if crude petroleum is placed in a suitable retort and gently warmed, each hydrocarbon will, at a definite temperature, its boiling point, distil over and can be

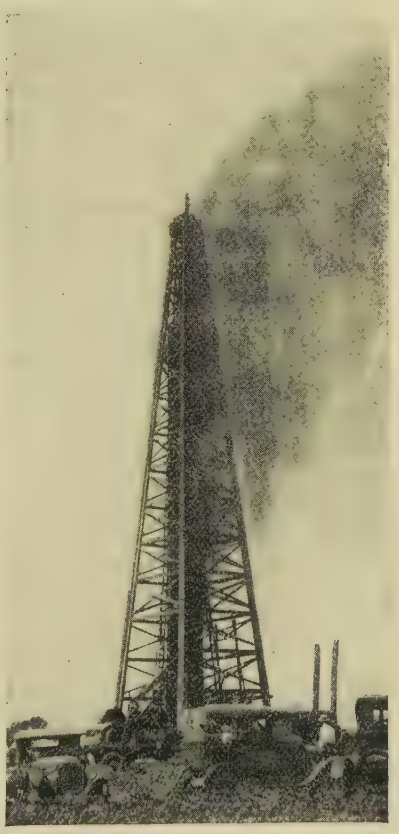


FIG. 368.—A GUSHER SPOUTING OIL.

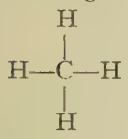
collected in a suitable receiver. This mode of separation is known as **fractional distillation.**

In general, the simpler the composition of the hydrocarbon, that is, the smaller the number of its atoms, the lower the temperature required for its distillation, and it also generally happens that these more volatile components are the most inflammable. One of the earlier products to separate from crude petroleum is **petrol** or **gasolene.** This substance, for which there is an ever-growing demand owing to the various uses of the petrol engine, is composed of the hydrocarbons hexane, C_6H_{14}, and heptane, C_7H_{16}. Since the boiling point of the former is 71° C. (about 160° F.), and that of the latter is 99° C., the mixture called petrol distils over while the crude oil is being heated between these temperatures. At temperatures a little higher, the two fuels **naphtha** and **benzine** distil over. When the temperature reaches about 150° C. the important illuminating oil **kerosene,** commonly called paraffin, is obtained. Kerosene is composed of members of the series ranging from decane, $C_{10}H_{22}$, to hexadecane, $C_{16}H_{34}$, and these do not all distil at 150°, but at temperatures between 150° and 300° C. The substances remaining in the retorts yield lubricating oils and useful solid hydrocarbons, including paraffin wax, employed in candle making and also for insulation in the electrical industries, and vaseline.

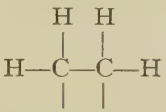
The process of oil refining is by no means simply a matter of fractional distillation; the oils, particularly kerosene, must be freed from such impurities as sulphur and certain unwanted hydrocarbons. These undesirable hydrocarbons belong to two series different from the paraffins: the *Olefine* series, which includes ethylene, C_2H_4, the chief illuminant in coal gas, and has the general formula C_nH_{2n}, while the other series is represented by C_nH_{2n-2} and acetylene, C_2H_2, is a member (Chapter XXXIV). Petroleum oils are separated from these substances by washing with sulphuric acid. The oil industry has now reached such dimensions and the products are so numerous that a special course in oil technology is a feature of some colleges, particularly the Imperial College of Science and Technology at South Kensington and the Sir John Cass Technical Institute.

An important fact concerning the various homologous series of hydrocarbons must be noted. The valency (Chapter XXXV) of carbon is four; it is tetravalent; and this means that in a compound such as marsh gas, CH_4, the carbon is satisfied with the number of hydrogen atoms, and is said to be *saturated*, but in ethylene, C_2H_4, the hydrogen atoms are insufficient to satisfy completely the carbon atoms, and the compound is an *unsaturated* hydrocarbon. These conditions are illustrated more clearly if **graphic** or **structural formulae** are employed. Compare the formulae of the two gases mentioned:

Marsh gas



Ethylene



The lines or bonds | indicate that in the case of ethylene the carbon valency is unsatisfied, in spite of the fact that one carbon atom helps to satisfy the valency of the other.

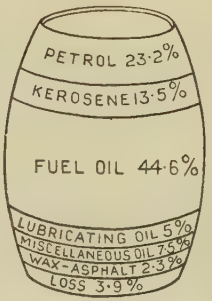
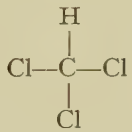


FIG. 369.
THE AVERAGE RESULTS OBTAINED FROM THE DISTILLATION OF A BARREL OF CRUDE OIL.

The paraffins are saturated, but the olefines and members of the acetylene series are unsaturated hydrocarbons.

Though hydrocarbons are not acids in any way, it is possible in certain cases to substitute a halogen element in place of one or more atoms of hydrogen. When three hydrogen atoms in marsh gas are replaced by three chlorine atoms, a compound which has been of the greatest service to mankind is produced. This substance is the volatile liquid **chloroform**, $CHCl_3$, and its graphic formula is



(see also Chapter XII).

If iodine replaces three hydrogen atoms in marsh gas the useful antiseptic **iodoform**, CHI_3, is the result. Similarly, **bromo-**

form, $CHBr_3$, a heavy liquid used in the laboratory for the separation of mineral fragments having different specific gravities, is obtained by the substitution of another halogen element, bromine, in place of three hydrogen atoms of methane.

SUGAR, ALCOHOL, AND BREWING

Many organic compounds, some of them important food-stuffs, are composed of carbon united with hydrogen and oxygen,

FIG. 370.—FIELD OF SUGAR CANE.
(Sena Sugar Estates, Ltd.)

present in the same proportions as they are in water. For this reason these substances are known as **carbohydrates,** and one of the most familiar examples is ordinary sugar, which has a composition represented by $C_{12}H_{22}O_{11}$. Cellulose, from which paper is made, is another carbohydrate and is described later.

When a piece of sugar is heated in a test tube, it first melts, then becomes brown, giving off vapours which have the characteristic odour of burnt sugar, and finally leaves a black residue of carbon. **Sucrose,** or sugar employed for domestic purposes, is

obtained from certain plants, particularly the sugar cane, a plant requiring a moist tropical climate, and the beet, a root cultivated extensively in temperate lands.

Cane sugar is obtained by pressing the canes between rollers, the juice being collected and then evaporated at a low temperature, so that the sugar is not decomposed by heat (Fig. 371). Brown prismatic crystals thus form in a thick liquor called *molasses*, from which treacle is obtained. The brown crystals of sucrose

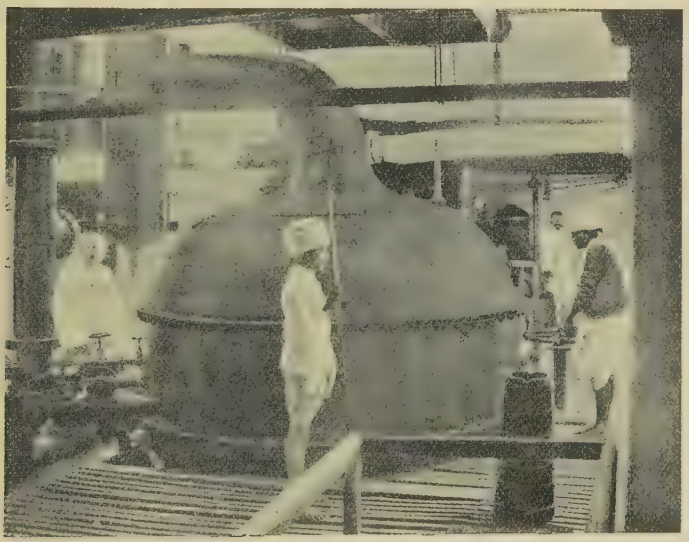


FIG. 371.—SUGAR—A VACUUM PAN.

are then purified by solution in water, and treatment with charcoal to remove colouring matter. On evaporation, crystals of pure sugar separate from the water.

In the case of beet sugar, the roots are cut into slices and immersed in water, when the sucrose is obtained in the form of a sticky substance which remains in suspension. In order to precipitate this matter, lime is added. Carbon dioxide is then used to convert the lime to carbonate which settles, and the sugar crystallises, after being purified by treatment with charcoal.

It is unnecessary to give here any description of the uses of ordinary sugar as it is too well known, but it may be noted that sugar candy consists of the crude brown prismatic crystals, and caramel is a brown colouring matter obtained when sugar is heated to about 200°, about 40° above its melting point.

The sucrose obtained from both plants, cane and beet, is identical in chemical composition, but there are other sugars, or *saccharine* substances, having a composition different from that of sucrose. Thus grape sugar or **dextrose** is found in grapes (and in the dried product raisins) and has the composition $C_6H_{12}O_6$. A sugar of the same composition is found in other fruits and is known as **fructose.** A sugar of this type can be prepared artificially by boiling starch with water in the presence of a small quantity of acid which acts as a contact agent, that is, as a substance the presence of which produces changes in other compounds.

FIG. 372.—GRAINS OF STARCH FROM A POTATO.

STARCH IS AN IMPORTANT RAW MATERIAL REQUIRED FOR THE MANUFACTURE OF GLUCOSE AND ALCOHOL.

Starch is a carbohydrate having the composition $(C_6H_{10}O_5)_n$, the n meaning that the group of elements occurs a very large number of times in a single molecule of the compound. On boiling with water, the starch takes up more hydrogen and oxygen in the proportions in which they occur in water:

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow n(C_6H_{12}O_6).$$

From the syrupy liquid thus produced, crystals of **glucose** are obtained. Starch occurs as little colourless granules in a great many plants, particularly potatoes (Fig. 372), maize, wheat (Fig. 373), oats, etc., and, as we have just seen, its conversion to a form of sugar is easily accomplished in the presence of

water. It is thus easy to understand why grape sugar is found in grapes and other fruit.

Now, when the juice of grapes is allowed to stand it slowly **ferments**, that is, the sugar in it undergoes a change which converts it to alcohol, causing wines to possess intoxicating properties. The change from grape sugar to alcohol is accompanied by the evolution of carbon dioxide gas, thus :

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2.$$
Alcohol

The process of alcoholic fermentation is not an ordinary simple decomposition of sugar, however, for some influencing material or contact agent is required for the change to take place, and this is supplied in the form of organic compounds called **enzymes**, contained in certain plants of a very primitive or simple type. Of these plants the unicellular organism yeast (Chapter V) is one of the most important, since it contains an enzyme, called *sucrase*, capable of splitting sugar into alcohol and carbon dioxide. Grapes contain their own yeast in the bloom on the skins, so that wines made from them are naturally intoxicating, but in the manufacture of beer, yeast is added to barley after the latter has been submitted to a preliminary treatment known as **malting** to convert its starch to a form of sugar called maltose. The barley is first cleaned, then steeped in water, and allowed to germinate, when enzymes convert the starch to sugar. The grains, which are dried carefully so as to preserve the enzymes, are then termed malt. In making beer, the malt is crushed, mixed with water and hops, and the mixture boiled for some time. When

FIG. 373.—STARCH GRANULES IN WHEAT.

THE STARCH OF FLOUR MIXED WITH WATER FORMS AN ADHESIVE PASTE EMPLOYED FOR HANGING WALL PAPER, ETC.

the liquid is again cooled to about 60° F. yeast is added, so that fermentation occurs and alcohol is produced. Finally, the yeast is skimmed off and the liquor put into large casks to mature.

The kind of water employed in these processes is an important factor in determining the nature of the final product. For pale ales, a hard water is more suitable, hence at Burton the natural waters of the river Trent, which flows across country containing calcium sulphate, or gypsum, are eminently suited to the brewing of this type of beer. On the other hand, the soft water of Dublin has been a factor in the production of stout. In modern times, owing to better chemical knowledge, a brewer can either harden or soften the water as desired.

Ales and stout contain relatively small proportions of alcohol (from 4 per cent. to 7 per cent.), and are of feeble intoxicating powers compared with whisky and other spirits, or with brandy obtained by the distillation of wines. These contain from 40 to 50 per cent. alcohol. Whisky is made from malt, but the treatment is prolonged, and distillation gives a product having a much greater proportion of alcohol than that in ale. The colour of whisky is due to the addition of caramel.

In their proportion of alcohol, which varies from 9 to 23 per cent., wines are intermediate between ale and whisky.

Ordinary alcohol is used for other purposes besides the production of whisky and ale. It is the solvent next in importance to water, and will dissolve substances, such as resin, that will not dissolve in water; consequently it is employed in the manufacture of varnishes, etc.

Methylated spirits, used for spirit lamps, etc., consists of ordinary alcohol mixed with a certain amount of *methyl* alcohol, obtained from wood spirits derived from the distillation of wood, which is added to make it objectionable as a beverage; colouring matter is also added.

There are several alcohols forming a homologous series, and the full name for the common kind occurring in wine, beer, and spirits is **ethyl alcohol.** The compositions of these alcohols will be understood better by reference to their relation to corresponding hydrocarbons.

By substitution of any one of the hydrogen atoms in certain hydrocarbons by a hydroxyl group (OH), an alcohol is derived thus :

Hydrocarbon.	Corresponding alcohol.
Methane, CH_4 or $CH_3 \cdot H$.	Methyl alcohol, $CH_3 \cdot OH$.
Ethane, C_2H_6 or $C_2H_5 \cdot H$.	Ethyl alcohol, $C_2H_5 \cdot OH$.

It will be observed that alcohols are not carbohydrates, as the hydrogen and oxygen are not present in the same proportions as in water. As a class, alcohols are inflammable and volatile liquids having a burning taste and characteristic odour, and they mix with water in any proportions. **Absolute** or pure **alcohol** is obtained by careful distillation, and by the absorption of remaining water by lime.

Though ethyl alcohol is not oxidised by atmospheric air in ordinary circumstances, yet under the influence of an enzyme produced by the minute vegetable organism, *Mycoderma aceti*, alcohol is oxidised by air with the production of **vinegar.** More correctly stated, vinegar consists of alcoholic liquor, which has become sour by the formation of **acetic acid.** Some fermented malt liquor, poor wine, or cider is caused to trickle over pieces of wood placed in large casks bearing holes to admit the air. The wooden material is previously treated with vinegar to ensure the presence of the necessary bacteria, and the resulting liquid or vinegar contains a small percentage (average 10 per cent.) of acetic acid.

The formation of acetic acid by the process is expressed by the equation :

$$\underset{\text{Alcohol}}{C_2H_5 \cdot OH} + O_2 \rightarrow \underset{\text{Acetic acid}}{C_2H_4O_2}{}^{*} + H_2O.$$

Pure acetic acid is a colourless liquid and is capable of forming a series of salts called acetates by replacement of one of the hydrogen atoms by a metal.

The oxidation of methyl alcohol produces the related organic substance formic acid, CH_2O_2 (or H . COOH), so called because it is secreted by ants (*formica*, an ant), and it is present in stinging nettles. When the acid is injected beneath the skin by either of these, irritating small white blisters are produced.

* CH_3COOH.

If a certain amount of hydrogen and oxygen, in the same proportions as in water, is taken away from an alcohol, a substance termed an **ether** is obtained. Common ether, used as an anaesthetic, is a colourless liquid derived from ethyl alcohol and has the composition $C_4H_{10}O$ (or $(C_2H_5)_2O$). As an anaesthetic it can function in two ways. When inhaled it produces general insensibility, the patient becoming unconscious, but when sprayed upon a certain part of the body it produces local numbness due to intense cold. Ether being very volatile absorbs much heat by its evaporation, hence the freezing effect of use in minor surgical operations.

THE MANUFACTURE OF SOAP AND PAPER

We have already noted the organic acids, acetic and formic. There are many others, and of importance in connection with soap making are the solid substances known as **stearic acid,** $H(CO_2C_{17}H_{35})$, **oleic acid,** $H(CO_2C_{17}H_{33})$, and **palmitic acid,** $H(CO_2C_{15}H_{31})$. Now, just as an alkaline substance, such as caustic soda, NaOH, can form a salt, say sodium chloride, by reaction with hydrochloric acid, so it can form an organic sodium salt by reaction with any of these organic acids. Thus sodium oleate or castille soap is formed by the reaction of caustic soda with oleic acid :

$$\underset{\text{Oleic acid}}{NaOH + H(CO_2C_{17}H_{33})} \rightarrow \underset{\text{Sodium oleate}}{Na(CO_2C_{17}H_{33})} + H_2O.$$

Sodium stearate and sodium palmitate are corresponding sodium salts of the other two acids, and ordinary common **soap** is a mixture of these three sodium compounds.

Hence ordinary soap could be made by heating caustic soda with a mixture of the three acids, but a better process is employed. Some naturally occurring substance which contains salts of these acids can be used, and the chief compound of this sort is **animal fat,** though vegetable oils obtained from olives, cotton seeds, etc., are of similar composition. Besides alkalis such as caustic soda, the alcohols may combine with these organic acids, but in this case the resulting compounds are termed **esters. Glycerine** is a

member of the alcohol family and forms by combination with oleic acid the ester known as glyceryl oleate :

$$\underset{\text{Glycerine}}{C_3H_5(OH)_3} + 3\underset{\text{Oleic acid}}{H(CO_2C_{17}H_{33})} \rightarrow \underset{\text{Glyceryl oleate}}{C_3H_5(CO_2C_{17}H_{32})_3} + 3H_2O.$$

Now, animal fat is composed of the esters glyceryl palmitate, glyceryl stearate, and glyceryl oleate ; consequently when fat is

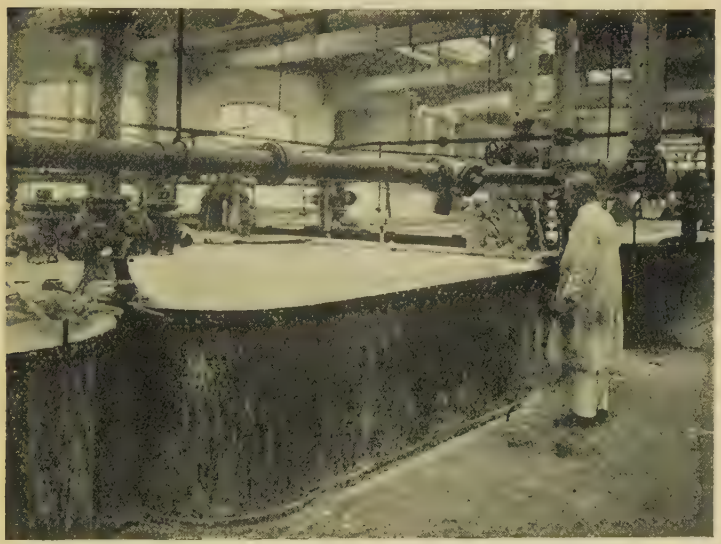


FIG. 374.—SOAP KETTLE.
(By courtesy of Messrs. Lever Bros.)

boiled with caustic soda a mixture of the corresponding compounds of sodium or soap is produced, and glycerine is set free. In the process of soap manufacture, common salt is added to the heated mixture and this causes the sodium compounds to collect at the top and form solid soap when cold. The glycerine is separated from the brine solution, and used for the manufacture of nitro-glycerine (an ester called glyceryl nitrate) and for medical purposes. The various coloured and scented soaps used for toilet purposes are produced by the addition of dyes and perfumes

to the ordinary soap, while soft soap is the result of substituting potassium compounds in place of caustic soda.

The cleansing power of soap results from the fact that it forms an emulsion with grease and takes up in suspension particles of dirt. The emulsion and suspended dirt can then be washed away from the object being cleansed. The reaction between soap and substances in water which cause it to be ' hard,' has been explained in a previous chapter (Chapter XXXIV). In the process known as dry cleaning, certain carbon compounds, such as benzine, which dissolves grease, are employed.

What happens if fat alone is boiled in water ? A mixture of palmitic, stearic, and oleic acids is obtained together with glycerine. The last two mentioned are then separated from the solid palmitic and stearic acids, which are mixed with paraffin and made into candles.

Among the numerous useful esters or compounds related to soap and fat are lard, butter, and the vegetable oils, some of which are used medicinally (castor oil), for culinary purposes (olive oil), and as a drying medium in paints (linseed and hemp oils).

Paper is an organic substance of much simpler composition, being derived from a carbohydrate called **cellulose.** Plants take carbon from carbon dioxide in the air, and combine it with water and nitrogen to make the various organic compounds of which they are composed. The walls of plant cells (Chapter V) and hence the hard framework of trees are composed of cellulose, the composition of which is $(C_6H_{10}O_5)_n$. Nitrogen enters into the composition of proteins, but not cellulose. The wood of pine and other trees is cut into small pieces and reduced to wood pulp by treatment with calcium bisulphite. This treatment is necessary because the cellulose of large plants like trees contains a similar but unwanted substance called lignin, which reacts with the calcium salt forming compounds that dissolve in water and can be removed by solution. The pulpy residue is more or less pure cellulose. Since the pulp lacks ' body,' it is mixed with powdered gypsum or clay to make it tougher, and because most varieties of paper are to be used with ink, the material is ' sized,' that is, mixed with some material such as alum, which produces a surface upon which ink does not run. The pulp thus

treated is pressed, rolled into sheets, and dried, the result being paper. Cotton fibre is practically pure cellulose without lignin, and the best qualities of paper are made from this source.

The world's annual consumption of paper is enormous and is a leading factor in the production of a vast lumbering or tree-

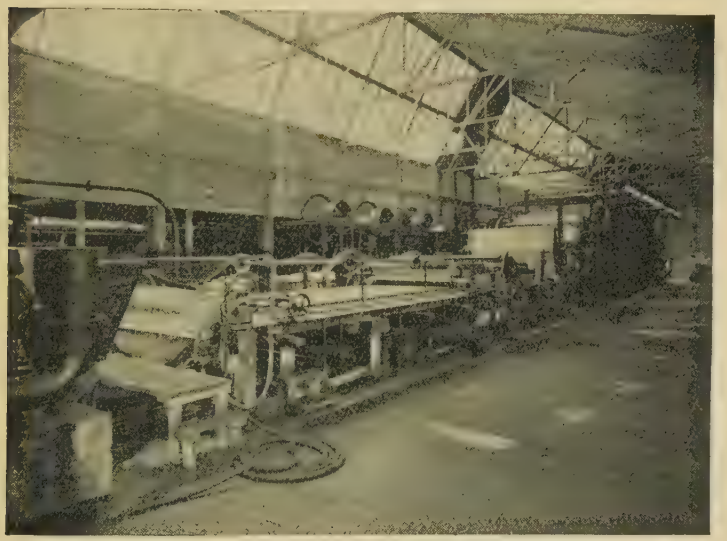


FIG. 375.—WET END OF PAPER-MAKING MACHINE.
(By courtesy of Messrs. J. Dickinson & Co., Ltd.)

felling industry carried on in Canada, Scandinavia, and other countries, particularly those having extensive forests of pine.

Within recent years wood pulp has been used for the production of **artificial silk** (celanese), which is made into stockings, underclothing, and dress materials. There are several processes for the production of artificial silk, but about 90 per cent. of the material manufactured is produced by the so-called **viscose process**. In this, the cellulose is first treated with caustic soda and carbon disulphide and the resulting substance, called cellulose xanthate, is then forced through fine jets into an acid or salt solution, where it coagulates in the form of fine filaments which can be united to form threads.

CHAPTER XLIV

RADIOACTIVITY AND THE STRUCTURE OF ATOMS

The end of the nineteenth century and the beginning of the twentieth witnessed many remarkable discoveries concerning the nature of extremely small though very real things, including particles of ordinary matter commonly termed atoms, particles of negative electricity or electrons, and ethereal waves of extremely short wave-length, called X-rays. Both physicists and chemists have contributed to our knowledge of these things, a fact which illustrates that our classification of scientific facts into separate groups, such as those labelled physics and chemistry, is done merely for our own convenience, and does not correspond to natural phenomena, which are not in reality sharply separated from one another.

In order to understand the connection between the physical and chemical aspects of radioactive phenomena, it will be as well to consider first certain facts discovered by electrical experiments performed by Sir William Crookes, Röntgen, and others towards the close of the nineteenth century. It was found by Crookes that when an electric spark from an induction coil was passed through a tube containing a gas, say air, at greatly reduced pressure, a stream of particles, called **cathode rays**, passed across the tube from the negative wire to the positive wire. An object placed within the tube casts a shadow, showing that the cathode rays produced really move along straight lines from the wire attached to the negative pole of the battery. The cathode rays can be deflected by a magnet, and we now know that these rays consist of **electrons** or particles of so-called negative electricity, that they are extremely small, one electron being only $\frac{1}{1800}$ the mass of an atom of hydrogen, and that, in the tube, they

travel at a high speed, the actual velocity of which is determined by the electric pressure and other conditions at the time. Free electrons passing as an electric current along an ordinary metallic wire travel with the speed of light, a rate greater than that of the cathode rays, within the vacuum tube. The conditions are different.

Crookes, who described cathode rays as *radiant matter*, showed that they were capable of causing the rotation of a little paddle wheel placed within the tube, thus demonstrating that the rays really consist of *something* capable of exerting a pressure.

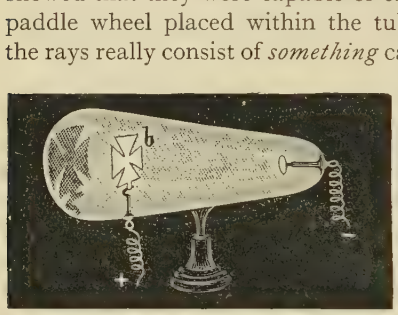


FIG. 376.—CATHODE-RAYS.
AN OBJECT IN THE PATH OF THE RAYS CASTS A SHADOW.

When the current was reversed the wheel rotated in the opposite direction, because the stream of particles always proceeded from the end of the wire which was negative.

When the cathode rays strike an object they are stopped, and as in the case of a rifle bullet hitting a target, much of the energy is then converted to heat. The temperature of an object struck by electrons rises, although it may be only a very small extent, and another thing happens; very short ethereal waves, called **X-rays,** discovered by Röntgen in 1895, are produced. In an X-ray tube a special target called the *anti-cathode* is placed so that the cathode rays are focused upon it (see Chapter XXXI).

Matter is really discontinuous, that is, its ultimate particles are separated by spaces, and X-rays, being of very small wave-lengths, can pass through minute gaps that are too small to allow the passage of the longer waves known as light.

Another most important fact concerning cathode rays is that, no matter what kind of gas is placed in the tube, and no matter what kinds of wires are used, similar streams of electrons or cathode rays are always produced, thus indicating that all these kinds of matter contain electrons. Quite recently, it has also been shown that any element against which cathode rays impinge

gives out X-rays, though the wave-lengths differ slightly according to the nature of the element forming the target. More is said about this later.

Now cathode and X-rays are not the only kinds of radiation produced when an electric discharge is passed through a vacuum tube. Streams of positively electrified particles having a faint violet luminosity travel in the opposite direction, along the tube from the positive towards the negative wire. These particles have been named **positive rays,** and much of our knowledge concerning the nature of atoms has been the result of **Sir J. J. Thomson's** researches upon these rays. For example, he has shown that each atom of a monovalent element contains a unit positive electric charge, an atom of a divalent element possesses two unit charges of positive electricity, and so on.

Consideration of space and the advanced nature of Thomson's work forbid an adequate account of it being given here, but it must be said that his analysis of positive rays ranks as one of the great achievements of modern science. According to Thomson's electronic theory of matter, any atom of any element contains electrons, but they are balanced by an equal charge of positive electricity so long as the atoms are electrically neutral. An atom becomes electrified positively because some of its electrons are torn from it by some disturbing factor, and negative electricity becomes apparent because some electrons are added to an atom originally neutral.

BECQUEREL RAYS AND RADIOACTIVITY

Certain substances become luminous or *fluoresce* under the influence of X-rays. The compound known as barium platinocyanide is one of these, and is used as a fluorescent screen placed behind objects submitted to the action of X-rays, so that parts of the object most transparent to the rays are represented by the more luminous parts of the screen and *vice versa.* Certain mineral substances, particularly those containing **uranium** and **thorium,** also become fluorescent when X-rays fall on them.

In 1896, one year after the discovery of X-rays, it occurred to **Becquerel** to repeat carefully certain experiments performed by

an earlier observer to see if fluorescent substances might themselves emit rays capable of penetrating objects and of affecting photographic plates.

He placed some uranium compounds against photographic plates covered by black paper and left these materials together in the dark for some time. When the plates were developed in the ordinary way, impressions of the objects containing uranium were found upon them, showing that salts of uranium produce radiations, called **Becquerel rays,** capable of penetrating paper which is opaque to light. For this reason substances which behave in this way are said to be **radioactive.** That rays do actually proceed from the substance itself is shown by the fact that the results are always the same whether the uranium salts are first exposed to light or not, and whether they are placed in a vacuum or not.

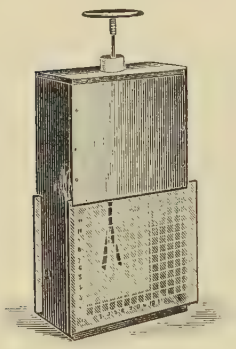


FIG. 377.—AN ELECTROSCOPE USED IN THE STUDY OF RADIOACTIVITY.

The rays must be derived from the substance and not from light or air.

Another important fact was also discovered by Becquerel, namely, that the rays proceeding from radioactive substances neutralise the electric charge on a gold leaf electroscope (Fig. 377). This instrument consists of two thin strips or ' leaves ' of Dutch metal, both connected to a metallic rod and suitably mounted in an insulating glass vessel. When an electric charge, either positive or negative, is given to the rod and leaves, the latter being mutually repellent diverge or spread out. A radioactive substance brought near a charged electroscope causes the leaves to collapse; because the air under the influence of the Becquerel rays becomes conducting, the air is said to be ' ionised.' The more radioactive a substance is, the more quickly do the leaves of the electroscope collapse, consequently the instrument is of great importance in the study of radioactivity.

Uranium occurs naturally in the mineral called **pitchblende,**

consisting mostly of uranium oxide. Another radioactive element, thorium, occurs in **monazite sands**, found in India and Brazil.

Thorium is employed in the manufacture of incandescent gas-light mantles, and if one of these is placed above a paper-covered photographic plate in the dark, and left for several days, an impression of the mantle is seen on the plate when it is developed (Fig. 378).

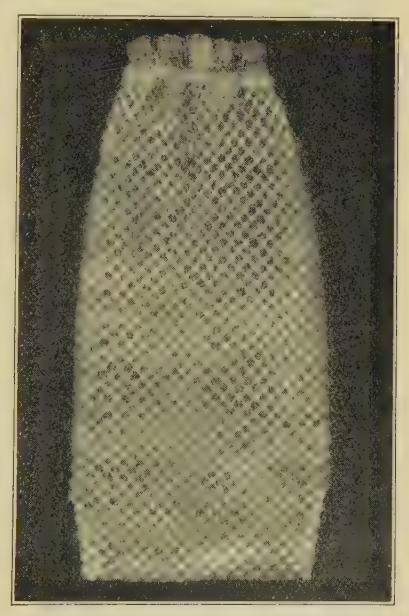


FIG. 378.—PHOTOGRAPHIC IMPRESSION DUE TO THE RADIOACTIVITY OF THORIUM IN AN INCANDESCENT GAS-MANTLE.

THE MANTLE WAS LEFT AGAINST A PHOTOGRAPHIC PLATE IN THE DARK FOR 4 OR 5 DAYS.

Now both uranium and thorium are extremely heavy elements, the atomic weight of the former, the heaviest known element, being 238, and that of the latter is 232. Radioactivity is a property exhibited by these heavy elements, because atoms of such substances are very complex in structure, contain a large number of electrons, are unstable, and susceptible to disintegration or a process of breaking up.

Some of the links in the chain of evidence upon which these statements are based must now be considered.

The very striking facts that the natural uranium ore, pitchblende, is much more radioactive than a prepared salt of uranium caused **Professor** and **Madame Curie** to carry out protracted investigations on that mineral in 1897.

After much labour, involving the treatment of great quantities * of ore, they succeeded in isolating a substance about a million

* About 30 tons of pitchblende yield only one gram of pure radium bromide.

times as radioactive as uranium. This substance was the chloride of a new element, called **radium.** Metallic radium itself was not isolated until 1910, when Mme. Curie obtained it by electrolysis of a solution of radium chloride. It is a light-coloured metal having an atomic weight of 226, and behaving towards water as metals of the alkaline earth do. It is related to calcium and barium, and like them is divalent, so that the formula for its chloride is $RaCl_2$.

Of course, both radium and its compounds exhibit radio-activity, the chloride or bromide being used for experimental work and medical purposes. In medicine, a certain amount of success has been achieved in the treatment of cancerous growths by rays emitted from these substances.

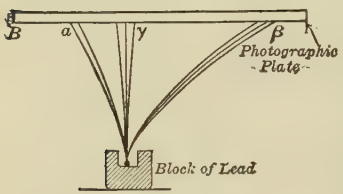


FIG. 379.

THE EFFECT OF A MAGNETIC FIELD UPON THE VARIOUS 'RAYS' EMITTED FROM RADIUM. THE β RAYS ARE MOST AFFECTED AND THE γ RAYS ARE NOT INFLUENCED AT ALL.

What is the nature of these rays? It has already been pointed out that they affect photographic plates and exert an influence upon a charged electroscope.

When pieces of paper or metallic foil are placed in front of the radium compound it is found that some but not all the rays get through these objects. Some of the radiations get through a block of iron many inches in thickness. When the rays are submitted to the action of a powerful magnet, it is found that some rays are attracted by the magnet more than others, while a third type of ray is quite unaffected by the magnetism. Evidently there are three distinct kinds of rays emitted by radium and other radioactive substances.

1. **The alpha rays** (or α-particles) are positively charged particles generally resembling the positive rays of a vacuum tube analysed by Sir J. J. Thomson. Their penetrating power is much less than that of the other rays, and the speed at which they are shot off from radium, though some 20,000 miles per second, is small compared with that of light. These particles are known now to be positively charged nuclei of the gas **helium,** derived from the breaking up or disintegration of atoms of radium. The visible

results of the impact of helium atoms or α-rays on a suitable target can be seen by a little instrument known as Crookes's spinthariscope (Fig. 380). In this, a small quantity of radium salt is placed on the tip of a pin placed within a tube and in front of a screen coated with zinc sulphide. A lens or eyepiece in front magnifies the result, and a faint flash of light is visible as each α-particle projected by the radium hits the sensitive screen.

The tracks along which α-particles (and those of electrons) move can be photographed by an ingenious method. Moisture in the atmosphere collects as drops formed upon dust particles which serve as collecting nuclei. In the same way atoms of helium and electrons can serve as nuclei, about which very minute drops of moisture can be precipitated, producing a fog.

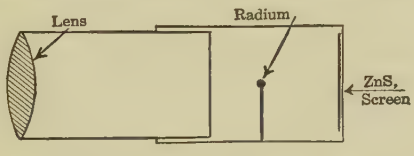


FIG. 380.—A SPINTHARISCOPE.

Consequently the pathway of a particle can be made visible by means of its *fog track*, when a radioactive substance is permitted to project its rays or particles through air saturated with moisture (Fig. 381).

The fog tracks of positive rays or α-particles are well-defined straight lines.

2. The **beta rays** (β-particles). These are electrons or particles of negative electricity. They travel with nearly the same velocity as that of light, about 180,000 miles per second. They are of the same nature as the cathode rays in a vacuum tube, but owing to the different conditions travel at much greater speed than the cathode rays do.

They are very much smaller and lighter than α-particles ($\frac{1}{1800}$ of the weight of an atom of hydrogen as stated above), so that their fog tracks are fainter, and are irregular lines, showing that the electrons cannot plough their way through the air in straight lines as the positive rays do. The β-rays are strongly bent aside by the influence of a magnet, and their power of penetrating

paper, etc., is greater than that of α-rays, though considerably less than that of X-rays.

3. The **gamma rays** (γ-rays) are not affected by a magnet and are not particles, but are ethereal waves of extremely short wave length. They penetrate objects much better than do either α- or

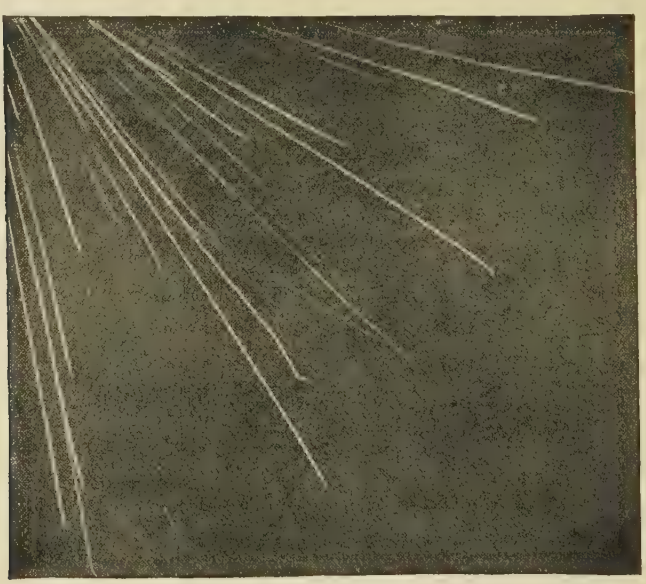


FIG. 381.—FOG TRACKS OF ALPHA PARTICLES PROJECTED FROM RADIUM.
(By courtesy of the Cambridge Instrument Company.)

β-particles, and generally appear to be identical with the X-rays produced when the cathode rays hit a target in a vacuum tube. It is believed that gamma rays are really very short X-rays.

THE DISINTEGRATION OF ATOMS

The researches of **Sir Ernest Rutherford** and **Professor F. Soddy** have shown that all these types of 'rays' are produced by the disintegration of atoms. We are not now considering ordinary chemical changes but structural changes taking place *within*

the atom itself. In the normal chemical reactions described in earlier chapters, the atoms in the compounds concerned retain their entirety, hence for those reactions the atomic theory of Dalton still holds good as a working explanation. Until quite recently, Dalton's view was generally accepted that every atom was indivisible—it could not be broken up. But now we know that some atoms at any rate do break up, and do so *spontaneously*, that is, of their own accord, without any help from us. It appears that nothing we can do either hastens or diminishes the rate at which atoms of radium disintegrate. We can hasten an ordinary chemical reaction, such as the preparation of oxygen in the laboratory, by heating the chemicals employed, but neither heating nor cooling radium influences its disintegration in the slightest degree.

In connection with this fact a very alluring problem—the harnessing of atomic energy—presents itself. The projection of rays into the surrounding matter by a radioactive substance is accompanied by the evolution of heat, a form of energy. The temperature of the radium compound is normally at a slightly higher level than that of surrounding objects. It has been estimated that radium gives out a quarter of a million times as much heat as a piece of burning coal of the same size does in the same time. But radium is obtained in small quantities, and these small quantities will not be hustled. Though a piece of radium will go on giving out its energy steadily for 2500 years at least, we cannot hasten the process; if we could, we should have solved the problem of using atomic energy for our own ends.

The searchers after the capture of atomic energy must bear in mind that should they succeed in accelerating the liberation of energy from radium or other substances, they will probably do so by the expenditure of considerable energy, so that the results gained will not equal the energy expended in the process. Should the harnessing of atomic forces become an accomplished fact, it is to be hoped that such knowledge will not be obtained until the degradation of science to the evil purpose of human destruction has ceased. The application of science to evil purposes is not the fault of science, but of those who misuse it, just as the

wrong expenditure of money is the fault of those who spend it thus.

Now, what is left of an atom of radium when an α-particle or nucleus of helium splits off from it? Rutherford in 1903 showed that a substance which he called the **radium emanation** was left, and has suggested atomic disintegration as the explanation of the phenomenon. The atom of radium by thus breaking up yields α-particles and an atom of the emanation. This emanation has since proved to be a very inert gas which was first named **niton**, but is now usually called **radon**. It has been collected, its atomic weight has been found to be 222·5, it has been liquefied, and even turned into a solid. But it slowly disappears because it is itself radioactive, producing more helium nuclei and a solid radioactive residue by its disintegration. Other products are produced by successive disintegrations. Thus a chain of disintegration products are produced, and the final product in which radioactivity ceases appears to be the metal lead. Since radium is derived by disintegration of uranium, the latter is the starting point, and it is a significant fact that uranium ores always contain traces of lead. It is interesting to note that lead resulting from the disintegration of uranium compounds has a slightly lower atomic weight than that obtained from galena, the usual mineral source. Two such varieties of the same element having different atomic weights are termed **isotopes**.

Certain facts concerning radioactivity have now supplied us with a new means of estimating the age of the earth. Since lead is the final product of radioactive changes, and the general uniform rate at which such changes take place being known, observations on lead residues in the various rocks of the earth have enabled geologists to calculate the time necessary for their production. From this evidence it is argued that the earth is between 1400 millions and 3000 millions of years old.

Another fact concerning the earth's history must not be overlooked. Radioactive substances are of widespread occurrence both in rocks forming the land and in oceanic waters, though at any one spot the amount of radium content may be very small. Yet, on the whole, there is in the earth radioactive material

equivalent to many thousands of tons of radium. The steady evolution of heat by the disintegration of this matter has helped to maintain the temperature of the earth such that a continuation of life for hundreds of millions of years has been possible. Without such a source of heat the earth would have had to rely solely upon the heat received from the sun.

Just as there is a chain of disintegration products in the case of uranium, so there is another chain of such products in the case of thorium, and yet another set of products commencing with the element called actinium. There are numerous materials for the study of radioactivity, and as stated previously, they all consist of heavy complicated atoms capable of throwing off helium and electrons.

Matter composed of aggregates of atoms is discontinuous, so are the atoms themselves. An atom of any element appears to consist of a small central nucleus, then a comparatively large space, and, next, one or more electrons revolving round the nucleus in much the same way as a planet revolves around the sun. In atoms of elements having low atomic weights, helium for example (Fig. 278), the number of revolving electrons is small, but in heavier elements, such as radium, there is quite a large number of revolving electrons. Since electrons are negative electricity, and an atom as a whole is neutral, the nucleus is composed of positive particles, sometimes called **protons**. In many cases electrons appear to form part of the nucleus as well. In an atom of hydrogen the positive nucleus consists of a single proton, around which is revolving a single negative electron.

An atom of helium contains a nucleus composed of four positive protons, together with two electrons, and there are two revolving electrons. Note that the total number of negative electrons in an atom is equal to the number of positive protons. In the case of an atom of uranium, there are no less than 92 revolving electrons, while its nucleus is composed of 238 protons together with 146 electrons. The atomic structure of uranium is unstable ; it breaks down spontaneously, throwing off protons and electrons. At each stage in the breaking-down process, an α-particle or a β-particle, or both, are thrown off, giving rise to a whole series of disintegration products and finishing up as lead.

Similarly, an atom of radium contains 226 protons and 138 electrons in its nucleus, and there are 88 revolving electrons. By the expulsion of an atom of helium, the residue radon is left with 222 protons, 136 nuclear electrons, and 86 revolving electrons in each atom.

A very important modern aspect of the subject developed by **Moseley** is based upon the fact that any element acts differently towards the production of X-rays from the way in which another element does.

When cathode rays strike an element, the wave-length of the X-rays produced depends upon the element used. The higher the atomic weight of the element the shorter the wave-length of the resulting X-rays. In this way a series of wave-length numbers known as the **X-ray spectra** of the elements is obtained, and these spectra afford a more accurate mode of classifying the elements than that afforded by atomic weights. According to the spectra, a series of **atomic numbers** is obtained, each element occupying a fixed position in the scale, and having its own number, and it is found that this figure also denotes the number of revolving electrons in its atom. Thus, the atomic number of hydrogen is 1, and there is one revolving electron in the atom; that of helium is 2, that of radium is 88, and uranium is number 92.

The general chemical properties of the elements bear a much closer relation to their atomic numbers than they do to their atomic weights. In the middle of the nineteenth century the famous Russian chemist **Mendeleéff** arranged a periodic table of elements, and showed that as a rule the chemical properties of any element bears some relation to its atomic weight, but in Moseley's atomic numbers we have a more successful generalisation.

As fresh discoveries are made and new facts obtained, it becomes necessary at times to adjust our views to the new evidence. Former theories may have to be restated or even relinquished where necessary; and scientific progress depends largely upon this readiness of its devotees to face new facts. The essence of science is *method*, and an impartial attitude towards facts so that truth may be found. In years to come our present

conceptions of atoms, their properties, and many other things may be profoundly modified, but in these chapters an attempt has been made to express the more elementary facts as they appear to us *now*.

The chief value of science lies in its ability to uplift mankind by improving the conditions of everyday life, and the adaptation of theories to new facts is a part of this process of advancement.

QUESTIONS AND EXERCISES

[*Questions marked* C.S.C. *are taken from papers set at Civil Service Commission Examinations, with the permission of the Controller of H.M. Stationery Office ; and those marked* O. and C. *are from Examinations of the Oxford and Cambridge Schools Examination Board.*]

PART III.

CHEMISTRY.

1. Enumerate the constituents of air, and state in what proportions they are present.

2. How would you demonstrate the fact that air contains approximately 20 per cent. of oxygen ? [O. and C.]

3. What do you understand by the terms 'elements and compounds' in chemistry, and on what grounds is a substance deemed to be an element ? [C.S.C.]

4. Write what you know about the rusting of iron, and refer to experiments in support of the facts you mention. Describe and explain some devices in use for the prevention of rusting. [C.S.C.]

5. What is understood in chemistry by the term combustion ? Give examples. Describe the luminous coal-gas flame and state what is supposed to take place in each part. [C.S.C.]

6. Explain the process by which the air can be liquefied.

7. How is oxygen usually prepared in the laboratory ? Sketch the apparatus required. Describe the properties of oxygen.

8. What do you understand by a *mixture* and by a *compound* ? Give examples of each.

9. How would you show that air contains a large proportion of a gas which does not aid combustion ?

10. What is the composition of iron rust ? How could you prove this experimentally ?

11. What is tinplate and galvanised iron, and why are they so useful ?

12. What is *reduction* ? How may the oxygen be removed from copper oxide ?

13. How does hydrogen differ from (*a*) oxygen, (*b*) nitrogen.

14. Describe two different methods by which hydrogen may be obtained from water.

15. Describe in detail an experiment by which you would make an accurate determination of the composition of water (either by weight or volume). . . . [O. and C.]

16. How is hydrogen prepared in the laboratory and how is it obtained in large quantities for commercial purposes ?

17. What salts are dissolved in sea water ? Explain how you would determine the proportion of dissolved matter in a sample of sea water.

18. What is ' hard water ' ?
How is water made ' soft ' for domestic and industrial purposes ?

19. Give examples of reactions in which substances (*a*) combine with water, (*b*) decompose water, (*c*) are decomposed by water. [O. and C.]

20. Explain what is meant by the terms 'synthesis ' and 'analysis.' Give examples.

21. Explain what is meant by dissolved and suspended impurities in natural water. How can these be removed ?

22. What is meant by the statement that the chemical equivalent of zinc is 32·5 ?

23. By what chemical process is acetylene produced, and for what purposes is it used ?

24. Why is hydrogen used to fill balloons ? What other gas can be used in place of hydrogen, and what advantage is gained by its use ?

25. State and explain the law of definite proportions.

26. Give a short account of the Atomic Theory, and show how it accounts for the laws of chemical combination. [O. and C.]

27. Define the terms 'atom ' and ' molecule.' What is meant by the equation

$$Zn + H_2SO_4 = ZnSO_4 + H_2,$$

and how would you test its truth ? [O. and C.]

28. What is meant by the 'valency' of an element ? Mention cases in which an element may exhibit different valencies.

29. Say what you know of the theory of *phlogiston*, and explain the part played by Lavoisier in disproving it.

30. How much metallic iron may be obtained by the complete reduction of 5 cwt. of ferric oxide, Fe_2O_3 ?

31. Explain carefully the full significance of the equation

$$Mg + 2HCl \rightarrow MgCl_2 + H_2.$$

32. State the law of multiple proportions, and explain it by reference to the oxides of iron.

33. What is the molecular weight of a substance ? Calculate the molecular weights of zinc oxide, ZnO ; ammonium sulphate, $(NH_4)_2SO_4$; and lead nitrate, $Pb(NO_3)_2$.

34. How could you find the weight of oxygen given off from five grams of potassium chlorate by heat ?

35. Under standard conditions of temperature and pressure one litre of pure hydrogen weighs 0·08987 gram. How much does a litre of nitrogen weigh under the same conditions ?

36. How would you prepare a sample of ammonia ? For what purposes are ammonia and its compounds used on a large scale ? [O. and C.]

37. How is synthetic ammonia produced on a large scale ?

38. State the general characteristics that distinguish (*a*) an acid, (*b*) a base. Define a salt, and give, with examples, three methods used in preparing salts in the laboratory. [C.S.C.]

39. What is a crystal ? How would you test the degree of symmetry of a crystal ? Explain simply the way in which X-rays have thrown light on the internal atomic structure of crystals.

40. How is sal-ammoniac manufactured, and for what purposes is it used ?

41. What is an 'alkali' ? Give the names of any alkalis known to you.

42. What is an acid ? Give the properties common to acids.

43. Explain carefully what takes place when hydrochloric acid and sodium hydrate solutions are mixed. What compounds are formed ?

44. Give equations representing (*a*) the combination of ammonia with water, (*b*) the neutralisation of nitric acid by ammonium hydroxide. Explain the equations.

45. Explain what is meant by the terms 'radicle' and 'ion.'

46. Describe the method of production of artificial ice by means of liquid ammonia.

47. What are allotropic modifications ? Describe the forms assumed by the element sulphur.

48. What are the chief properties of sulphur dioxide ? How is it prepared, and for what purposes is it used ? [O. and C.]

49. How does sulphur occur in nature ? Give an account of the properties and uses of this element. [O. and C.]

50. How would you prepare a small quantity of sulphuric acid from sulphur ? Describe the properties of sulphuric acid and account for its importance (*a*) in the laboratory and (*b*) in chemical industry. [C.S.C.]

51. Give an account of three useful sulphates, their composition and uses.

52. How is hydrogen sulphide prepared, and of what use is it in the laboratory ?

53. Describe briefly the usual commercial process for the manufacture of sulphuric acid.

54. Give an account of the Frasch method of obtaining sulphur.

55. Explain the part played by ferrous sulphate in enabling ink to give a permanent mark on paper.

56. What is an isomorphous series ? Illustrate by reference to the alums, and name any other isomorphous series you know.

57. Describe the reaction that takes place when metallic sodium is placed upon water.

58. What is the composition of (*a*) baking soda, (*b*) washing soda ? Explain their chief uses. [O. and C.]

59. How would you prepare (*a*) hydrochloric acid from common salt, (*b*) chlorine from hydrochloric acid ? Describe some of the uses of hydrochloric acid and chlorine. [O. and C.]

60. What is meant by ' catalysis ' ? Describe some chemical processes which depend upon the presence of a catalyst. [O. and C.]

61. Soda is one of the cheapest and commonest of household chemicals. Explain why it can be produced so cheaply : outlining very briefly any one process in general use for making it. What are the properties that make soda so useful in the household ? [C.S.C.]

62. Explain the principle of spectrum analysis.

63. What are the natural sources of salt, and how is it obtained from them ?

64. Describe the preparation and collection of chlorine gas. What are the properties of chlorine ?

65. For what purposes is chlorine used industrially ? How is bleaching powder prepared ?

66. How is hydrochloric acid prepared in the laboratory ?

67. How may a sample of nitrogen free from oxygen be obtained from air ?

68. Describe any natural or artificial processes by means of which atmospheric nitrogen is brought into combination. Why are such reactions important ? [O. and C.]

69. How is nitric acid prepared on a large scale, and for what is it used ? [O. and C.]

70. Describe the chief kinds of explosives employed for military or other purposes.

71. Describe the various oxides of nitrogen, and show how they support the law of multiple proportions.

72. What weight of nitric acid can be obtained from 3 tons 5 cwt. of saltpetre, $NaNO_3$?

73. Mention the chief nitrates and their uses.

74. Why is nitric acid said to be an oxidiser ? Describe an experiment to show its oxidising power.

75. On what chemical reaction do explosions depend ? Mention some important explosives, and say how they are obtained.

76. What is the nitrogen problem ?

Describe either the Birkeland-Eyde process or the cyanamide process of nitrogen fixation.

77. What are the properties of nitrous oxide, and how is this substance prepared ?

78. Describe the general properties of the metals.

79. How is lead manufactured from its ores ? For what purposes are the metal and its compounds used in industry ? [O. and C.]

80. Give a short account of the manufacture of pig-iron from iron ore. [O. and C.]

81. What is an alloy ? Describe several examples of useful alloys.

82. Outline the various stages in the production of (*a*) pure copper from copper pyrites, (*b*) tin from tinstone. [C.S.C.]

83. How is aluminium obtained ? Explain the uses of alumino-thermy.

84. Describe the manufacture of steel, and mention special varieties of steel used for certain purposes.

85. What are the chief compounds of iron which are used as ores ?

86. What is meant by the hardening and tempering of steel ?

87. What are the chief sources of copper ?

88. Explain why silver compounds are used in photographic processes.

89. Describe briefly the chief varieties of silica found in nature. Of what use are they ?

90. What is glass, and how is it made ? Describe the properties which chiefly contribute to its usefulness. [O. and C.]

91. In what natural forms do sulphates occur ? How is plaster of Paris made, and on what property does its value depend ? Describe the properties of any common sulphates with which you are familiar. [O. and C.]

92. How is lime prepared from limestone ? What are its uses ?

93. Describe some clays of commercial value, and explain how certain products are obtained from them.

94. How is carbon dioxide prepared in the laboratory ? Describe some industrial applications of carbon dioxide.

95. Theoretically, what weight of sand is required for the production of $\frac{1}{2}$ ton of common glass ?

96. What is water glass, and for what purpose is it used ?

97. What is the use of limestone which is mixed with iron ore during melting ?

98. Describe the chief properties of minerals by which a prospector identifies them.

99. State what you know of diamonds. How have diamonds been prepared artificially ?

100. How is each of the following obtained, and for what purpose is it used : lamp black, wood charcoal, graphite, anthracite ?

101. What do you know of the origin of coal ? Describe the differences in composition of peat, lignite, household coal, and anthracite.

102. Distinguish between producer gas and water gas. How is each gas prepared ?

103. Describe briefly the preparation and purification of coal gas, and give a list of its main constituents. Mention any important by-products obtained and their uses. [C.S.C.]

104. Point out the advantages of distilling coal. Enumerate the products obtained by this process and indicate the purposes for which they are employed. [C,S.C.]

105. Describe the various forms of carbon, giving some of the uses of each.

106. Explain the terms ' crystalline ' and ' amorphous,' using the case of carbon as an example.

107. Compare the properties of the diamond with those of graphite. How can it be shown that both of these substances are carbon ?

108. What is carborundum, how is it manufactured, and for what purposes is it used ?

109. Explain the terms combustion and flame. How do you account for the non-luminosity of the Bunsen flame ?

110. What is a hydrocarbon, and how does it differ from a carbohydrate ? Mention some useful hydrocarbons.

111. How does petroleum occur, and what is probably its origin ?

112. Describe the manufacture of soap. Why is more soap required to form a lather with some waters than with others ? [O. and C.]

113. What is an enzyme ? Illustrate your answer by reference to the manufacture of ale and vinegar.

114. What is a saturated hydrocarbon ?
Describe various products obtained by the distillation of petroleum.

115. What is cellulose, how is it obtained, and what important commercial products are obtained from it ?

116. How is ordinary sugar obtained from the sugar cane and from the sugar beet ?

117. What weight of residual carbon is obtained when a piece of sugar (sucrose) weighing 5 grams is carefully heated in a glass tube ?

118. What is starch, how does it occur, and of what use is it ?

119. Distinguish between ethyl alcohol, methyl alcohol, absolute alcohol, and methylated spirits ?

120. What are esters ? Mention some commercial products obtained from esters.

121. How is glycerine prepared, and what are its uses ?

122. Explain the cleansing action of soap.

123. Say what you know about cathode rays.

124. Discuss the part played by Professor and Madame Curie in connection with the study of radioactive substances.

125. Say what you know about α-particles and β-particles projected from radium.

126. Describe briefly the way in which uranium compounds disintegrate, yielding a series of disintegration products, the end product being lead.

127. What light has the study of radioactivity thrown upon the question of atomic structures.

128. Explain why an incandescent gas mantle placed upon a photographic plate in the dark makes an impression upon the plate.

129. What is fluorescence ? Name substances which fluoresce under the influence of X-rays.

130. Describe a spinthariscope and explain the phenomenon seen by its aid.

ANSWERS TO NUMERICAL QUESTIONS.

CHEMISTRY.

30. $3\frac{1}{2}$ cwt.
33. 81 ; 132 ; 331.
35. 1·259 gm. approx.
72. 2 tons 8 cwt. $19\frac{1}{2}$ lb.
95. 7·5 cwt. approx.
117. 2·1 gm. approx.

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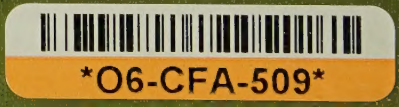
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